ISSN: 1525-3066

Center for Policy Research
Working Paper No. 117

THE VALUE OF STATISTICAL LIFE: PURSUING THE DEADLIEST CATCH

Kurt E. Schnier, William C. Horrace,
Ronald G. Felthoven

Center for Policy Research
Maxwell School of Citizenship and Public Affairs
Syracuse University
426 Eggers Hall
Syracuse, New York 13244-1020
(315) 443-3114 | Fax (315) 443-1081
e-mail: ctrpol@syr.edu

October 2009

$5.00

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Abstract

Observed tradeoffs between monetary returns and fatality risk identify estimates of the value of a statistical life (VSL), which inform public policy and quantify preferences for environmental quality, health and safety. To date, few investigations have estimated the VSL associated with tradeoffs between returns from natural resource extraction activities and the fatality risks they involve. Furthermore researchers have been unable to determine whether or not one's VSL is stable across multiple decision environments using revealed preference methods. Understanding these tradeoffs (and the VSL that they imply) may be used to inform resource management policy and safety regulations, as well as our general understanding of the value of life. By modeling a commercial fishing captain's choice to fish or not, conditional on the observed risk, this research investigates these topics using data from the Alaskan red king crab and snow crab fisheries. Using weather conditions and policy variables as instruments, our estimates of the mean VSL range from $4.00M to $4.76M (depending on the modeling assumption and fishery analyzed) and are robust to the incorporation of heterogeneous preferences. Furthermore, given the unique nature of the data we are able to conduct an intra-vessel comparison of the VSL and conclude that for roughly 92% of the fishermen observed in the data set their VSL estimates are stable across both fisheries.

Kurt E. Schnier[ϕ], Department of Economics, Andrew Young School of Policy Studies, Georgia State University, P.O. Box 3992, Atlanta GA 30302-3992, kschnier@gsu.edu; William C. Horrace, Department of Economics & Center for Policy Research, Syracuse University, whorrace@maxwell.syr.edu; Ronald G. Felthoven, U.S. National Marine Fisheries Service, Alaska Fisheries Science Center, ron.felthoven@noaa.gov

Keywords: value of statistical life (VSL); intra-agent VSL comparison; Alaskan crab fisheries.

JEL Codes: J28; Q22

[ϕ] Corresponding author. Phone: 404.413.0159; Fax: 404.413.0248. The authors would like to thank Jennifer Lincoln (NIOSH Alaska Field Station) and Charlie Medlicott (USCG-Dutch Harbor, AK) for their extensive help in providing information on the risks present within the Alaskan crab fishery. Funding for this research was provided by the National Science Foundation (NSF) and the National Marine Fisheries Service. The lead author would also like to thank the Property and Environment Research Center (PERC) who graciously provided funding to initiate this project while a Lone Mountain Fellow during the summer of 2007.

I. Introduction

Society often faces choices that involve tradeoffs between physical risk and pecuniary returns, and our decisions reveal our willingness to trade money for the risk of physical harm (Ashenfelter 2006).[1] "The ratio of the wealth we are willing to accept in exchange for a small change in the probability of a fatality is expressed in units of 'dollars per death,' or the dollar value of a fatality. It is for this reason that this tradeoff is often called the value of a 'statistical' life" (Ashenfelter 2006, pC10). To date, little attention has been paid to the empirical investigation of the value of a statistical life (VSL) in high-risk natural resource extraction industries.[2] In addition, empirical researchers have been unable to conduct an intra-agent stability test on their implied VSL measures. This research investigates both of these topics using a unique data set on fishing behavior in Alaskan crab fisheries, recently popularized as "The Deadliest Catch," in a period during which two exogenous policy changes have altered the physical risks within the fishery. Methodologically our estimates of the VSL control for the endogeneity of risk, sample selection biases (Ashenfelter 2006; Ashenfelter and Greenstone 2004) as well as heterogeneous preferences. Our results illustrate that fishermen operating within the Alaskan crab fisheries possess a VSL strikingly similar to those observed in the literature. This indicates that these individuals are no more risk-loving than the general population because the risk premium they receive for the physical risk they incur is consistent with the general population's preferences. Furthermore, our agent-specific estimates of the VSL are stable across two different work environments possessing different risk-return tradeoffs. This later discovery is the first observed, to the best of our knowledge, within the VSL literature and supports the theoretical supposition that an agent's VSL is an unchanging latent element of one's decision heuristic.

In 2006 commercial fishing became the riskiest occupation in the United States. According to the Bureau of Labor Statistics (BLS), the fatality rate for fishermen was 141.7/100,000 workers, which is substantially greater than the national average of 3.9/100,000 workers (BLS 2006). Commercial fishing risk is a direct function of the common-pool nature of the resource which often generates a "race for fish" within fisheries. That is, if a fishery is managed with a fishery-wide total allowable catch (TAC), it creates incentives for fishermen to fish as quickly as possible before the TAC is reached and the fishery is closed for the season. When fisheries are managed in this way, the race may generate risky behavior on

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[1] The theoretical foundation for the risk-wealth trade off and the Hicksian compensation variation were initially derived by Jones-Lee (1974).

[2] Thaler and Rosen (1976) did utilize fishermen in their pioneering hedonic wage research. However, the fatality risk rate used was 19/100,000 workers which is substantially different than current measures of the fatality risk rate in fisheries. Smith and Wilen (2005) investigate how fatality risk influences spatial decisions in the California sea urchin fishery. However, they are unable to use their results to obtain an estimate of the VSL within this fishery.

the part of the participants, and we typically observe rent dissipation and excess capacity within the fishery relative to the socially optimal level (Cheung 1970; Gordon 1954; Smith 1968, 1969). Although many fisheries can be characterized as a regulated open-access fishery (Homans and Wilen 1997) because they possess a fishery wide total allowable catch (TAC) and licenses that may not be obtainable by all (e.g., license limitation program), rent dissipation is still a dominate feature as fishermen "race for fish" generating a "tragedy of the commons" (Hardin 1968).

The use of property rights to mitigate the tragedy of the commons has proven successful in a number of different natural resource environments (Hannesson 2004; Libecap 2006; Neher et al. 1989). Aside from increasing economic efficiency, property rights substantially reduce the incentive to race.[3] If such behavior is positively correlated with risk, the creation of property rights in fisheries may reduce the inherent risks within the fishery. With mitigation of these risks in mind, two policy changes in the Alaskan crab fisheries have been recently enacted: 1) the United States Coast Guard (USCG) Pre-Season Boarding Program and 2) the transition to property rights management under the Bering Sea and Aleutian Island (BSAI) Crab Rationalization Program (BCRP). These programs affect behavior and risk in the Alaskan red king crab and snow crab fisheries and are, hence, sources of exogenous variability which we use as instruments to identify and estimate the VSL. We also employ daily variation in weather conditions to the same end. Our approach is in the spirit of Ashenfelter and Greenstone (2004), but our particular data set possesses features that make it ideally suited for such an analysis and that allow us to investigate some additional concepts related to the VSL which have not been investigated in the literature to date. More specifically, we estimate the first intra-agent comparison of the VSL to investigate stability in one's risk-return preferences across different environments using revealed behavior. These issues are discussed throughout the paper.

Valuing health and life as a commodity can be troubling because "we can not produce life years directly or buy them in any market. Goods that can not be produced or sold often become priceless through a natural process that leads to independent utility considerations, great concerns for equity, probing discussions of obligations to the future, and assertions that these goods shall not be allocated through the market" (Fuchs and Zeckhauser 1987, p267). Therefore, the only way the value of life can be estimated is using indirect methods. Viscusi (1993) outlines three indirect methods that can be used to estimate the VSL: 1) survey methods, 2) risk trade-offs inside of the labor market, and 3) risk trade-offs

[3] Fisheries managers within the United States refer to "property right" management regimes as limited access privilege programs (LAPPs) because they are in fact revocable privileges bestowed upon fishermen which for the most part have not been revoked (Bromley 2009). For simplification we will refer to a LAPP as a property right throughout the paper.

outside the labor market. Survey methods allow researchers to consider a broad spectrum of risk profiles and not just those observed within the environment of labor markets. These methods have been used to investigate the mortality risks associated with pesticide use (Evans and Viscusi 1991; Viscusi et al. 1987), respiratory ailments (Viscusi et al. 1991; Krupnick and Cropper 1992), the effect of age on the VSL (Krupnick 2007), and traffic safety (Hultkrantz 2006), to cite a few. Risk trade-offs in the labor market are traditionally investigated using hedonic wage decomposition models (Rosen 1986; Thaler and Rosen 1976), which regress observed wages on the work related fatality rate with additional control variables for job- and agent-specific characteristics. Hedonic wage decomposition models have been used extensively in the literature; Viscusi and Aldy (2003) cite over 60 different studies that have utilized this method to estimate the VSL. However, there are a number of empirical issues that may bias the VSL estimates within hedonic wage decomposition models. The three most commonly cited are measurement error, omitted variable bias, and the endogeneity of fatality risk (Black and Kniesner 2003; Ashenfelter and Greenstone 2004; Ashenfelter 2006; Kniesner et al. 2006). Due to these shortcomings, this research uses observed non-labor market risk tradeoffs to estimate the VSL.

Measuring the implied VSL outside of the labor market utilizes the theory of consumer behavior and observed decisions to investigate individuals' money-risk tradeoffs. The earliest investigations focused on the implied VSL resulting from highway speeding (Ghosh et al. 1975) and the use of seat belts (Blomquist 1979). Since then, there have been investigations into: revealed willingness to pay to avoid hazardous waste sites and pollution using property values (Gayer et al. 2000; Portney 1981), automobile accidents using data on new automobile prices (Atkinson and Halverson 1990), and vehicle safety and fuel economy standards (Dreyfus and Viscusi 1995). The primary difference between studies conducted outside of the labor market and those within the labor market is that in the former the implied risk-money trade-off the consumer faces is directly observed whereas in the later it is decomposed into a risk-wage premium.

Our approach, based on the captain's decision to fish or not on a given day, estimates his marginal rate of substitution (MRS) for fatality risk and economic reward, which is converted to a VSL by multiplying the MRS by the ratio of observed revenues to the fatality risk faced by each vessel. We then calculate an average VSL for the fishery. This is methodologically similar to the approach of Ashenfelter and Greenstone (2004) who examine the adoption of higher speed limits on rural interstate highways. However, given that our measure of economic reward comes from data on crew and captain remuneration at the conclusion of a fishing trip it does utilize similar information used in labor market analysis. We estimate our model using data from the Alaskan red king crab and snow crab fisheries over the years 1997-2007. Furthermore, we correct for three important econometric issues which may bias VSL estimates in general: the endogeneity of risk, sample selection bias (Ashenfelter 2006) and heterogeneity in decision agents (Shogren and Stamland 2002). To control for the endogeneity of risk we employ the two policy changes and contemporaneous weather conditions as instruments for daily fatality risks. Given that our estimates of the VSL are only observed for those fishermen who decide to fish on a given day, our estimates of the VSL are subject to sample selection bias and represent an upper bound on the true VSL. To correct for this we conduct a two-stage Heckman sample selection model (Heckman 1979) in the spirit of Ashenfelter and Greenstone (2004) and Ashenfelter (2006) to estimate the true underlying VSL in each fishery. Finally, to account for heterogeneity in the decision agents we estimate a finite mixture model using vessel-specific information to define their vessel type.

Our empirical analysis yields VSL estimates that lie between \$4.00M and \$4.76M, depending on the model estimated. These estimates are stable across the two main fisheries in which crab fishermen participate, the Alaskan red king crab and snow crab fisheries, and are robust to the modeling of heterogeneous risk-return tradeoffs. Furthermore, using the unique nature of the decision environment, we are able to conduct an intra-vessel comparison of fishermen's individual VSLs implied by their revealed behavior in the two fisheries studied. Our comparison illustrates that for roughly 92% of the fishermen participating in both fisheries studied their implied VSLs with each fishery are not statistically different from each other. This finding is remarkably novel because, to the best of our knowledge, this is the first time that researchers have been able to conduct an intra-agent VSL analysis.

In the following section we provide a general discussion of Alaskan crab fisheries, introduce our data, and provide a descriptive discussion of how policy changes have affected risk, revenues, capital utilization, and crew size in the fisheries. Section III outlines our modeling approach and discusses our VSL results with and without heterogeneous vessel behavior. Finally, Section IV summarizes and suggests some additional avenues for research in this area.

II. Fishery and Data Description

With their high fatality rates, the Alaskan crab fisheries have long been recognized as one of the riskiest occupations. For the most part this is due to the seasons during which these fisheries are executed (late fall for red king crab and winter for snow crab). Fishermen battle adverse seas and inclement weather to harvest crab. During the time period studied (1997-2007) there were two policies enacted which changed the inherent risks within the Alaskan crab fisheries: The USCG Pre-Season Boarding Program and the

BSAI Crab Rationalization Program (BCRP).[4] The first policy change occurred in October of 1999 and it required each crabbing vessel to be boarded by the Coast Guard prior to the fishing season, so they could assess vessel safety and stability (unstable vessels can tip and loose crew or capsize) and have vessel operators correct any identified safety hazards. Furthermore, each vessel has to receive a Dockside Exam Decal from the USCG, assuring that their vessel meets the safety requirements for the vessel, before it is issued a fishing license and allowed to fish in the crab fisheries in each season. The second program began in October 2005 (right before the Alaskan red king crab fishery season), when the crab fisheries shifted from a limited-entry common-pool fishery to a rights-based fishery in which individual transferable quotas were allocated based on historic catch levels.[5] Our *a priori* expectations regarding the impacts of these policies are that they both reduced the risks present in the fishery (holding weather constant). The following section is a brief discussion of the Alaskan crab fisheries and these policies. Our purpose is not to evaluate the effectiveness of these programs in mitigating risk in the fishery. Our purpose is simply to argue that these programs are valid instruments affecting fatality risk in estimating the VSL.

Fatality rates in the Alaskan crab fisheries have historically been among the highest recorded for any fishery across the globe. Figure 1 plots the annual fatality rates per a 100,000 workers for all of Alaska and for the federally managed Alaskan crab fisheries over the years 1990-2007 with vertical lines indicating the timing of the USCG Pre-Season Boarding Program and the BCRP.[6] Prior to the inception of these programs, fatality rates were nearly five-times the average fatality rate in all of Alaska (the "overall" rate includes crab fatalities). Following these programs fatality rates dropped by nearly two-thirds and the annual crab fatality rates fell more in line with the average fatality rates for all Alaskan fisheries. Thus, these programs seem to have affected risk in the fishery and are excellent sources of exogenous variability. Just prior to the inception of the BCRP, the fatality rates increased substantially within the Alaskan crab fisheries, but this is primarily due to one event. On January 15, 2005 (opening day of the last season before rationalization for the snow crab fishery) the fishing vessel "Big Valley" sank and five crew members perished in the Bering Sea. This vessel left port *before* being inspected under

[4] Prior to the time period studied, the Commercial Vessel Safety Act was passed in 1988, which established the initial safety requirements for commercial fishing vessels (Sorum 2003). However, given that this did not occur during the time period studied we have elected to not discuss this policy in detail.
[5] The first crab fishery affected by the BCRP was actually the Alaskan golden king crab fishery that precedes the Alaskan red king crab fishery, but it is a much smaller fishery and it is not studied in our analysis.
[6] Source data used in Figure 1 was obtained from Jennifer Lincoln at NIOSH, Alaska Field Station. It is important to note that a smaller-scale inshore state fishery exists for the two species studied and recently fatalities have occurred within these fisheries. However, these fatalities are not included in our analysis because they are not regulated under the BCRP.

the USCG Pre-Season Boarding Program and if removed from the data set (indicated by the "Big Valley" dashed line in Figure 1) it substantially reduces the fatality rate, which is still nearly three times the fatality rate for all Alaskan fisheries in 2005.

In 2005 the BCRP was launched. Under this program a quota allocation program was implemented with quota being divided among individual eligible harvesters, processors, captains, and local communities[7]. Eligible vessel owners and captains received individual transferable quotas (ITQs) which awarded them a fraction of the seasonal total allowable catch (TAC) and processors received individual processor quota (IPQ) which awarded them the rights to process a given percentage of the TAC. The final group allocated quota were the local communities who received community development quota (CDQ) which consisted of approximately 10% of the seasonal TAC (NOAA 2007). The allocation of both ITQs and IPQs was enacted in an attempt to address concerns over the market power that either the processors or harvesters might possess if all the quota were allocated to only one of the these groups (Anderson 1991; Clark and Munroe 1980; Matulich et al. 1996; Matulich and Sever 1999). The BCRP allocated quota shares for all federally managed crab fisheries in the BSAI. In each of the crab fisheries fishermen formed harvester cooperatives to aggregate ITQs aboard vessels and to allocate the harvesting decisions among the participating vessels within the cooperative in the post-BCRP period. This research will focus on the species being targeted during the two primary fishing seasons in the BSAI, the fall season beginning in mid-October and the winter season beginning in mid-January. In the fall season the target species is king crab (*Paralithodes camtschaticus* and *P. playpus*), dominated primarily by red king crab (*Paralithodes camtschaticus*). In the winter season there are two target species, snow crab (*Chionoecetes opilio*) and tanner crab (*C. biardi*) with snow crab being the dominant species by catch volume.[8] Throughout the paper we will refer to the fall season as the red king crab fishery and the winter season as the snow crab fishery.

The formation of cooperatives facilitated the reduction in physical capital employed within the fishery, which had accrued to a high level in the "race for fish" era (prior to the BCRP), and it had a dramatic effect on both the number of active fishing vessels and the length of the fishing season. Figure 2 shows the number of vessels participating in each fishery by year, and the days fished each year. As is evident in the figure, season length (days fished) and the number of vessels fishing are inversely related, which is precisely what would be expected given the prevailing fishery conditions prior to rationalization.

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[7] Select rural communities also earned the right to purchase processor quota to prevent processing jobs from leaving their communities.

[8] The tanner crab fishery is now managed as two separate regional fisheries, the eastern and western tanner crab fisheries.

Following the inception of the BCRP (post-2004 for the red king crab and post-2005 for the snow fishery due to the fall and winter starts in each fishery, respectively) the number of vessels dramatically decreased in both fisheries, while season length increased[9]. Although the number of vessels dramatically decreased following the BCRP, a direct result of the cooperatives, this does not imply that the total amount of fishing effort fell. In raw numbers labor participation fell dramatically but when controlling for the length of the season the full-time equivalence (FTE) of effort remained relatively stable.

Figure 3 shows the total FTE employment rates by year. Given that the season lengths were short prior to rationalization (due to the "race") and that fishermen are exposed to risk the entire time they are on board the vessel, we constructed our FTE measure as the total number of days fished for each vessel times 24 hours times the number of crew members divided by the normal annual work hours for non-seasonal jobs (2000 hrs; 40 hrs./wk multiplied by 50 weeks year).[10] The trends in FTEs in Figure 3 suggest that the number of FTEs dropped in 2000 for both fisheries, dramatically so in the snow crab fishery. This time period was characterized by a large reduction in the total allowable catch (TAC) within both fisheries which in turn led to fewer fishing days and a reduction in FTEs. For instance, in the red king crab fishery the catch fell 30.13% from 1999 to 2000 (NPFMC 2006) and in the snow crab fishery it fell 82.73% over the same time interval. Since 2000, the annual landings (catch) in the red king crab fishery have increased, causing a rebound in the FTEs (NPFMC 2006). In the snow crab fishery the annual landings have remained low, relative to the 1999 level, generating a more stable FTE profile in the years following 2000. Controlling for these conditions, the FTEs in both fisheries have remained relatively constant over the past ten years, indicating that the BCRP has not dramatically reduced the level of human capital employed. The primary effect has been a reduction in both the number of vessels (physical capital) and individuals employed (variable capital), but an increase in the utilization and duration of employment for the remaining vessels and crew.

One of the arguments for implementing the BCRP was that it would increase the safety of fishermen by eliminating the "race for fish" that prevailed in this fishery (NOAA 2006).[11] The safety argument

[9] It should also be noted that 23 out of the 155 vessels that left the fishery did so before implementation of the BCRP in the vessel buyback program, which was not formally part of BCRP (the list of vessels included in the buyback is located in the federal register notice at http://www.nmfs.noaa.gov/mb/financial_services/buyback_docs/reduction_payment_tender_notice.pdf)

[10] We do not observe the number of hours worked by each crewmember on board the vessel. However, the crew are at risk the entire time they are at sea so we have elected to construct our FTE measure assuming 24 hours of risk exposure. As a result, the measure of FTEs or changes in FTEs reported here may not represent the most useful metric for examining changes in employment in the post-rationalization period. See http://www.fakr.noaa.gov/npfmc/current_issues/crab/leasingPractices509.pdf for a detailed discussion.

[11] The objectives of the BSAI Crab Rationalization Program are outlined on the National Marine Fisheries Service's website. The link is http://www.fakr.noaa.gov/sustainablefisheries/crab/rat/progfaq.htm#wicr .

hinges[12] in large part on the fact that weather-related vessel instability is the leading cause of vessel accidents and death within the Alaskan crab fishery (Lincoln and Conway 1999; Lucas and Lincoln 2007) and that fisherman could now afford to elect to not fish on high-risk days (since their catches are now secured through property rights). Under the BCRP, captains may be more inclined to wait for good fishing weather because they are guaranteed the privilege to land a pre-specified quantity of crab, their ITQ. This would tend to reduce the number of tipping and capsized vessels and improve the on-deck work environment, preventing individuals from being swept overboard, and the risk of death and injury within the fishery.[13] This said, delivery contracts between vessels and processing plants still exist and may influence the rate at which the vessel fishes, or the weather conditions in which they must fish. The behavioral impacts of this are further discussed in the empirical modeling section.

Data Description

The vessel landings data for all vessels that participated within the red king crab and snow crab fisheries for the years 1996-2007 were obtained from fish tickets filed with the Alaska Department of Fish and Game (ADF&G) commercial fisheries catch accounting system.[14] Each fish ticket contains confidential information on the date a vessel left port to begin fishing, the date it returned to offload the catch, the port at which the catch was landed, the amount landed, the price per pound received for the catch, and the gross revenues earned on the trip. To obtain information on the vessel's physical capital structure (i.e., vessel length, net-tonnage, horsepower, fuel, hold capacity etc.) we utilized data from the Alaska Commercial Fishery Entry Commission vessel registration files. Confidential data on the number of crew members aboard the vessel as well as the revenues received by the captain and crew were obtained from the NMFS Economic Data Reports (EDR).[15] The fatality rate data were obtained from the

[12] Another safety-related argument is that crew members may no longer have to fish around the clock as they had to do to compete in a race-for-fish scenario, which creates extreme fatigue and increases the likelihood of accidents. However, as we discuss later, crew fatigue and a rapid fishing pace is still present in the fisheries. This is likely due to a continued desire to minimize days at sea (which are costly), increased catch and quota levels by the vessels that continue to fish, and persistence of the work ethic of individuals who have been historically employed largely because of their ability to work fast for long periods of time. This said, some vessels have begun to utilize two different crews to sequentially participate in the fishery to lower crew fatigue within the season and to allow them time off the vessel to spend with their families.

[13] Roughly 27% of the fatalities that occurred within the Alaskan crab fisheries are a result of being swept overboard.

[14] Data for 1996 was used to initiate the data used in the analysis and we can not use data prior to 1996 because the red king crab fishery was closed in 1994 and 1995.

[15] The EDR data was recorded in 1998, 2001, 2004-2007. For the pre-rationalization years in which no EDR data were collected, we used vessel-specific averages from other pre-rationalization years to impute crew size and earnings as a percent of gross revenues, assuming crew compensation rates were roughly constant aboard each vessel in the pre-rationalization years.

National Institute of Occupational Safety and Health, Alaska Field Station and indicates the date the fatality occurred, the location within the BSAI, the cause of the fatality, and the vessel on which the fatality occurred. This information is used to construct fishery-specific daily moving averages of the fatality rate using one-year moving averages.[16] For a more detailed discussion of the data utilized and variable construction see Appendix A.1.

Table 1 contains descriptive statistics for the two crab fisheries broken down by pre- and post-rationalization (BCRP) periods.[17] Although the descriptive statistics indicate that the average annual revenues within the snow crab fishery in the pre-rationalization period are greater than those within the red king crab fishery, this is a result of the substantially higher TACs within the snow crab fishery in the pre-2000 time period. Comparing annual revenues in the post-2000 time period within the snow crab fishery with the red king crab fishery indicates that the annual earnings in the two fisheries are very similar. This said the average daily earnings in both fisheries indicated that the average daily earnings in the red king crab fishery are a little over twice those in the snow crab fishery. This difference is primarily due to the difference in the ex-vessel price recorded in each fishery. Specifically, the mean ex-vessel price recorded in the red king crab fishery was $5.19 per a pound (2007 $s), whereas it was $1.28 per a pound (2007 $s) in the snow crab fishery. The average trip length doesn't statistically vary within the snow crab fishery across pre- and post-rationalization periods, where as it does within the red king crab fishery. The shortened average trip length observed in the red king crab fishery prior to the BCRP is primarily due to the temporal constraint imposed by the shortened season, whereas the averages observed in other time periods primarily reflect the capital limitations (e.g., filling the live hold, described below) of the vessels participating in the fishery. Mean trip length illustrates another pre-rationalization timing issue within the red king crab fishery: the length of time a vessel is moored waiting to offload their catch. The maximum reported trip lengths are longer than the actual fishery openings and this is due to boats being backlogged at port at the end of the season waiting to offload their catch. Crab can live for an extended period of time in the live holds, and vessels often wait at port to offload. However, should the vessels wait too long, crab will be begin to die and fishermen will incur a "dead-loss" which can substantially reduce their trip revenues. Because waiting at the dock will directly influence the trip revenues, but not fatality risk exposure, we truncate the trip length for all trip tickets that report landings

[16] Alternative moving averages were investigated as well (2-year and 3-year) which generated similar profiles of risk. Because of this, as well as our desire to use as many years of data as possible prior to the USCG Pre-Season Boarding Program, we elected to use a 1-year moving average with data from 1996 used to initiate the 1997 values.

[17] We do not break down the descriptive statistics into pre- and post-USCG Pre-Season Boarding Program because this policy did not have any effect on the capital structure or season length.

two days beyond a fishery closure to account for the time fishermen may spend getting back to port if they are on the fishing grounds when the closure occurs.[18]

Another notable phenomenon in Table 1 is that fixed capital structure is heterogeneous. Vessel length, horsepower, and net-tonnage vary substantially across the fleet. However, the most notable and production-relevant form of heterogeneity is the vessel hold capacity (reflecting the volume of the tanks in which live crab are stored), which possesses a standard deviation slightly below its mean in all cases. This heterogeneity in fixed capital will be utilized in the empirical model to help explain the intra-fleet differences in revenues.

Another meaningful pre- and post-rationalization change in Table 1 is in landings per vessel (Total Lbs. (yr.)), expressed in annual pounds of crab delivered to processors, and the daily earnings of the captain and crew on board the vessel. Given that much of the quota allocated through the program based on historical catch has been pooled by quota owners within voluntary fishing cooperatives for the execution of the fishery, many of the vessels in the cooperatives fished for more than the individual allocation they earned (while other vessels did not participate in crab fisheries but were paid royalties for their quota). Calculating the total landings for each active vessel in the fleet following the BCRP, we see a fair degree of heterogeneity in catch volume. However, the statistics do show that (for the most part) vessels participating in these fisheries landed much more crab after rationalization. To investigate this further we calculated the ratio of each vessel's pre-rationalization landings for the three years prior to the BCRP to their post-rationalization landings, conditional on the vessel actively fishing in all years following the BCRP, the average ratio was 3.34 and 1.96 in the red king and snow crab fisheries respectively.[19] Given that vessels were awarded quota based on historical catch rates[20], this indicates that those vessels that participated in the post-rationalization era executed a cooperative consolidated ITQ that was between two and three times their own individual ITQ allocation. This is consistent with the contraction in capital utilization within these fisheries during this time period(see Figure 2).[21] Although the annual landings per vessel increased following the BCRP, the daily earnings for the captain and crew

[18] Anecdotally, our dock interviews of captains and crew members participating in these fisheries support this data assumption.

[19] We estimated this ratio using only those vessels that fished in all years following the BCRP to account for the temporal adjustment in the capital restructuring and cooperative formation following rationalization. Calculating this statistic using the raw data reported in Table 1 results in a ratio of 4.29 and 1.39 in the red king crab and snow crab fisheries respectively.

[20] Details on the criteria used to make the allocations can be viewed at http://www.alaskafisheries.noaa.gov/regs/680/table7.pdf

[21] It should be noted that while vessel numbers have dropped considerably, quota ownership has only marginally consolidated. As of 2008, there were 245 quota owners in the red king crab fishery compared to 251 at the inception of the BCRP. In snow crab the number has gone from 241 quota owners down to 231.

decreased. This is a direct result of the decreases in crab prices (linked to large increases in Russian crab in the market) as well as changes in the remuneration rates following the BCRP as the costs of ITQ leases are often subtracted from the gross revenues before crew and captain shares are calculated. Additional factors that may have reduced the *daily* revenues are extended soak time for the pots being fished and shorter work cycles as fishermen are no longer "racing" to catch the crab.[22] The net result is that the average daily revenues fell approximately 30% and 17% in the red king crab and snow crab fisheries, respectively, after imposition of the BCRP.

III. Empirical Model

To estimate the VSL we employ an empirical framework similar to that used by Ashenfelter and Greenstone (2004) and outlined in Ashenfelter (2006). On a given day t a vessel captain i decides between fishing and not in a given crab fishery f (red king or snow crab). If she fishes, $Fish_{itf} = 1$ (zero otherwise), the crew (and captain) face an expected time and fishery-specific fatality risk f_{tf}, to earn an expected individual economic return, R_{itf}. If the captain decides to fish on a given day, she is implicitly deciding that the returns from fishing exceed the costs associated with the probability of a fatality. From this implicit tradeoff, we can recover an estimate of each captain's marginal rate of substitution between return and risk and then construct an estimate of the VSL. Following Ashenfelter and Greenstone (2004), we let V be the upper-bound estimate of the VSL from the sample of captains that decided to fish (no selection correction) and let V^* be the selection corrected estimate based on Heckman's (1979) selection model.

Estimating V

To recover our initial estimates of the vessel-specific tradeoffs being made within the red king and snow crab fisheries we estimate an earnings regression to recover a captain's marginal rate of substitution for risk. Using the fish ticket data we approximate the average daily gross revenues obtained per vessel per fishing trip.[23] That is, R_{itf} is total net revenues paid to captain and crew for each fishing trip divided by

[22] The data show that longer soak times lead to increased catch per pot, creating the incentive for longer soak times. However, the increases in catch per pot decrease as the number of days soaked increase, which may decrease the crab caught and thus revenues received per day. However, the additional soak time is not particularly costly if the crew happens to be engaged in pulling or setting other pots and generates greater revenues for the trip overall.

[23] The revenues per day are in thousands of dollars and converted to 2007 dollars using the consumer price index (CPI). A "trip" as defined in the analysis results from the trip start and delivery dates from fish ticket records. In some cases we found fish tickets from deliveries that included overlapping dates; in these instances we defined the trip length as a union of the trip dates from the fish tickets and the trip revenues as the union of total trip revenues.

the number of days for that trip. Therefore we are assuming that over the course of a fishing trip the earnings per day are unchanged. As such, the daily revenues for each vessel do not vary within a trip but do vary across trips. Fundamentally, it is this variation that we utilize to estimate the VSL. Ideally we would determine what revenues were obtained for each vessel on each day, but we do not observe daily production data for all vessels. Therefore, we construct daily revenue estimates by apportioning trip revenues across days fished, which may introduce some estimation bias. Fish ticket data only contain *gross* revenues. To convert the gross revenues to net revenues received by the captain and the crew, the EDR data was used to calculate vessel-specific shares of the gross revenues allocated to the captain and crew respectively. Given that all are on the vessel at the time of fishing the two are added together to construct R_{itf}. In the pre-rationalization period roughly 38.2% and 36.6% of the gross revenues were allocated to the captain and crew in the red king crab and snow crab fisheries respectively. This changed to roughly 23.9% in both fisheries following rationalization. The changes in the pre- and post-rationalization shares is primarily due to the fact that many active fishermen following rationalization paid a lease rate on the quota they fished for their other cooperative members. These additional expenses effectively reduce the portion of gross revenues paid to the crew and captain (as some portion is now used to pay for the additional quota), but not necessarily their total earnings, since gross revenues increase as larger quantities of quota are fished. The regression model we estimate for each fishery is,

$$\begin{aligned}\ln(R_{itf}) = R(X_{itf};\beta_f) = \beta_0 + \beta_1 \ln(price_{itf}) + \beta_2 \ln(length_i) + \beta_3 \ln(hp_i) + \beta_4 \ln(hold_i)\\ + \beta_5 USCG_{tf} + \beta_6 BCRP_{tf} + \beta_7 \ln(GHL_{tf}) + \beta_8 \ln(fatal_{itf}) + \varepsilon_{it} \quad , \qquad (1)\end{aligned}$$

where X_{itf} is a vessel, time and fishery-specific observation matrix. The vessel specific variables, $length_i$, hp_i and $hold_i$ are vessel's length, engine horsepower and hold capacity, respectively, which are the fixed production inputs. For approximately 10% of the data one of the vessel characteristics was missing. To account for this we utilized propensity score nearest neighbor matching to impute the missing values (Rosenbaum and Rubin 1983, King et al. 2001). The policy dummy variables, $USCG_{tf}$ and $BCRP_{tf}$ capture the USCG Pre-Season Boarding Program and BCRP, respectively. For the red king crab fishery the USCG took effect in 1999 whereas it took effect in 2000 for the snow crab fishery. Similarly the BCRP took effect in 2005 for the red king crab fishery and 2006

As a check on accuracy, we compared these trip lengths with similar data recorded in dockside interviews by the Alaska Department of Fish and Game, and with trip length data captured by the onboard GPS-based vessel monitoring system (VMS) data. As it is the mean "trip" length used in the analysis is similar to that reported in Table 1, which uses the raw fish ticket data. See Appendix A.1 for more detail.

for the snow crab fishery. The price variable, $price_{itf}$, is the recorded ex-vessel price received by the vessel at the processor at the time the fish was landed. This is used to control for price effects on the average daily revenues. The variable GHL_{tf} is the gross harvest limit for each fishery in a given year, which is set at a pre-specified percentage of the spawning stock biomass each year and is used to control for stock abundance and yearly harvesting constraints. The vessel-specific daily expected fatalities, $fatal_{itf}$, is the fishery-specific expected daily fatality rate, f_{tf}, multiplied by the number of FTE's onboard vessel i on day t (the sum of the captain and the crew).[24] This captures vessel-specific total expected fatalities that may result while at sea on a given day. The coefficient on this variable, β_8, captures the fleet-wide marginal rate of substitution between revenues and fatalities. We calculate f_{tf} as $f_{tf} = \max\left(AKf_t, Crabf_{tf}\right)$, where $Crabf_{tf}$ are the daily fatality rates for the crab fishery of interest, and AKf_t are the annual fatality rates for all fisheries operating in Alaskan waters (an overall commercial fleet risk rate). AKf_t is calculated as a one-year average of fatalities divided by FTEs at sea and based on the annual fatality risk data obtained from the NIOSH, Alaska Field Station. We construct the fatality rate in this way because the number of vessels participating in the crab fisheries is small relative to the number of vessels fishing in all of Alaskan waters, and we believe that the overall commercial fleet risk rates represent a minimum baseline level of risk that captains take into consideration in their fishing decisions. In addition, although the Big Valley, which sank on January 15, 2005, failed to be inspected by the USCG prior to leaving port we have elected to retain this fatality in our data set for two primary reasons: (1) *ceteris paribus*, removing these fatalities would bias our VSL estimates downward[25], and (2) our dock side interviews of fishermen participating in this fishery indicated that fishermen were highly cognizant of these fatalities.

One assumption of this model is that the captain cares for the welfare (both pecuniary and non-pecuniary) of his/her crew as well as herself in their risk-return tradeoff. That is, captains value their lives as equal to the value of a crew member's life (If not, there would be separate MRS coefficients for captain and crew in Equation 1). Based on this specification, a consistent estimate of V (the sample-selection

[24] Jin and Thunberg (2005) in their study of fatality risks within the northeastern United States model fatality risk as a logistic probability function which they are able to estimate given all the fisheries encompassed in their study. This method is intractable in our environment because we are only focusing on two fisheries. Furthermore, there fatality risk measures are annually based whereas ours vary by day. This method may prove to be advantageous in future empirical work if expanded to a broader set of fisheries within the United States.

[25] The upward bias was confirmed in our preliminary regression analysis when we removed these fatalities from our data set. The VSL estimates were roughly $1M larger, depending on the modeling assumption, than those illustrated for the snow crab fishery within this paper.

upper bound on the VSL) is the product of a consistent estimate of β_8 and a measure of expected revenues, divided by a measure of expected fatalities. For example, using our regression results we estimate a daily, vessel-specific $\hat{V}_{itf} = \hat{\beta}_8 R_{itf} / fatal_{itf}$, where $\hat{\beta}_8$ is a consistent estimate of the MRS.[26] One important limitation of this construction, and for most VSL studies, is that the measure of a captain's value of statistical life depends explicitly on the ratio of returns to fatalities.[27] Holding a vessel captain's marginal rate of substitution and the risk profile constant, a reduction in the daily returns will also reduce the implied VSL for the vessel (as the captain took on a given amount of risk for less compensation). However, the opposite holds true for days with high returns, and the goal of the model is to estimate the average VSL for the prevailing risks and returns observed in the fishery using the daily variation in returns and expected fatalities. This said, in a subsequent section, we will discuss in more detail the standard deviation of our daily vessel-specific VSL measures as they reflect the degree of variability in our VSL estimates and can be utilized in our intra-agent comparison of the VSL estimates.

Within this decision environment, it is difficult to believe that the risks, f_{tf}, are exogenous. That is, it is the decision of a captain to fish or not to fish that explicitly determines the risk that she (and the crew) faces. If she elects not to fish, this clearly affects the number of vessels and crew at risk and, hence, our risk measure. In some sense our measure of average daily risk over the past year (the daily moving average) will mitigate this problem, but instruments for risk are at our disposal and we use them in a two-stage least squares exercise. In addition to the two dummy variables for policy changes we include wave height and an inclement weather variable, defined as the PPR index obtained from an icing nomogram.[28] In the red king crab fishery the PPR index controls for inclement weather because vessel icing is not a significant factor within this fishery, whereas in the snow crab fishery it indicates the degree of vessel icing risk present. We hypothesize that inclement weather and vessel icing is an important determinant of risk because it reduces vessel stability and increases the probability of capsizing. Wave height, not used in the calculation of the PPR, is also an important component of fatality risk, and we use the average daily

[26] We do not contend that a captain's VSL is changing daily and ultimately report average VSL over time and vessels. However, we do not impose the time-invariant assumption *ex ante*.

[27] A similar discussion of this relationship was elaborated on in more detail in Jones-Lee (2004) in his theoretical model of the interaction between a developed and developing countries VSL in public policy when cross-country externalities are present.

[28] The weather buoy data used in the analysis comes from station 46035. More information on this buoy can be obtained at the following link: www.ndbc.noaa.gov/station_page.php?station=46035 . The buoy data used is the closest weather buoy to the fishing grounds within the BSAI that contained consistent data for the years 1997-2007. The PPR index is a transformation of weather data (wind speed, water freezing point, air temperature, and sea water temperature) which is used to predict vessel icing. Although icing is not a factor in the red king crab fishery, we use the PPR to indicate inclement weather because it non-linearly transforms these different measures of weather into a single index.

wave height reported by the NOAA weather buoy 46035 within the BSAI.[29] The results from our first stage estimation results are contained and discussed in the Appendix (See Table A.2). F-statistics for the two first stage regressions were 14.97 and 61.97 for the red king crab and snow crab fisheries respectively, validating our choice of instruments in both fisheries.

The results from the second stage regression (Equation 1 with instrumented fatalities $fatal_{itf}^{IV}$) are in Table 2. Across both fisheries studied, the results indicate that larger vessels (indicated by the length and hold capacity variables) and more mobile vessels (indicated by vessel horsepower) earn higher daily revenues. Furthermore, as would be expected, years with a higher ex-vessel price per a pound generate larger daily revenues. Finally, the statistically significant and positive coefficient on GHL illustrates that in years that the spawning biomass stock (and therefore the GHL) was larger, the mean revenues within the fishery increased, holding all else constant (i.e., the ex-vessel price effects). All of these results are consistent with our expectations and across the two fisheries studied. On the other hand, the results for the two policy shifts differ across both fisheries. Within the red king crab fishery daily revenues increased following the USCG Pre-Season Boarding Program and decreased following the BCRP. However, the increased revenues following the USCG Pre-Season Boarding Program cannot be attributed to the policy itself, because this time period corresponds with a time of stock recovery following the near collapse of the red king crab fishery in the early 90's. The finding of a reduction in daily revenues following the BCRP was not statistically significant, but the direction of this impact is consistent with what one would expect. As discussed earlier in the paper, the race for fish was eliminated. As a result the pace of fishing slowed somewhat due to longer soak times for the pots used to catch crab, and as such, daily compensation fell on average (although total seasonal compensation did not). Within the snow crab fishery, the reduction in revenues resulting from the USCG Pre-Season Boarding Program is capturing a time period in which the snow crab fishery was under going a sizeable restructuring following the mid-1990s. During this time period the seasons was shortened (see Figure 2), the FTEs fell (see Figure 3) and the GHL was reduced, following the high catch levels in mid-90s, and, as was the case with the red king crab fishery, does not completely reflect the impact of the policy directly. Likewise, because the BCRP time period also corresponds with a time period during which the opposite occurred, the dummy variable is capturing this effect.

The coefficient of primary interest is that on instrumented daily fatalities, $fatal_{itf}^{IV}$, because it is an estimate of the marginal rate of substitution of revenue and risk within the fishery. Scaling this

[29] In some cases buoy data were unavailable, so we let these values be zeros and included a dummy variable in the regression equal to 1 if the data were missing and zero otherwise.

coefficient by the ratio of the vessel-specific daily returns to the vessel-specific expected daily fatalities, we are able to recover a daily measure of each vessel's VSL, $\hat{V}_{itf}$. These can be averaged over time and vessels to produce a fleet-wide VSL, $\overline{\overline{V}}_f$. This estimate represents an upper bound on the true VSL, because it excludes vessels that did not fish because their expected revenue was too low relative to the fatality risk of fishing, and, hence, their implied (and omitted) $\hat{V}_{itf}$ would have been relatively lower had it been observed.[30] This upper bound on the fleet-wide VSL is approximately \$4.59M and \$5.78M (2007 dollars) in the red king crab and snow crab fisheries respectively (see Table 2). The value of these estimates are greater than those reported in the transportation risk literature (Ashenfelter and Greenstone, 2004) but within the range reported within the general VSL literature (Viscusi, 1993; Viscusi and Aldy 2003).

Sample Selection Model

As discussed earlier, to consistently estimate the true underlying V^* we must account for the sample selection present in the model (Ashenfelter 2006; Ashenfelter and Greenstone 2004). To estimate V^* we use the observed $\hat{V}_{itf}$ as the dependent variable in the main equation of a Heckman (1979) sample selection model. However, to recover the inverse mills ratio we must first estimate the probability that a captain decides to fish on a given day. The following probit model is estimated to recover this probability:

$$\begin{aligned}&\Pr(Fish_{itf}=1)=\omega_0+\omega_1 ExpRvn_{itf}+\omega_2 USCG_{tf}+\omega_3 BCRP_{tf}+\omega_4 days_{itf}+\omega_5 days_{itf}^2+\omega_6 del_{itf}\\&+\omega_7 Quota_{itf}+\omega_8 Strike_{tf}+\omega_9 no\_weather_{tf}+\omega_{10} PPR_{itf}+\omega_{11} PPR_{itf}^2+\omega_{12} PPR_{ift}^3+\tau_{itf}\end{aligned} \quad .(2)$$

$ExpRvn_{itf}$ are vessel-specific daily expected revenues from fishing in fishery f during time period t. It is calculated using a lagged moving average of the vessel-specific daily estimated trip revenues derived within the fishery in the previous year.[31] $days_{itf}$ is the cumulative number of days that a vessel has been fishing within a given season and fishery. This variable captures the degree of state

[30] There are number of other factors that may contribute to a captain's decision to fish or not on a given day which we will control for in the sample selection correction of the VSL.

[31] Vessel-specific estimates of the expected revenues are utilized to control for the heterogeneous nature of the fleet. In the case that a vessel did not fish in the previous year, rendering the moving average zero, we imputed the average value for the entire fleet.

dependence present in the fisherman's decision, which has been well illustrated to influence fishermen behavior within the literature (Holland and Sutinen 2000; Smith 2005; Schnier et al. 2009). del_{itf} calculates the number of days until a vessel's next delivery in the post-BCRP era. Within the post-rationalization period vessels delivery dates were set up with the processors and this variable proxies for the length of time the vessel has until they have to make their next delivery. This variable was constructed by determining the length of time from the current day until the next delivery date recorded within the data with non-fishing days included in the calculation. $Quota_{itf}$ represents the remaining available quota that a vessel has yet to land at each day during the season. It would logically follow that if they are out of quota they will stop fishing. This variable is constructed by summing up each vessel's landings in the post-BCRP period and then determining what percentage of their landings that year they had executed at a given point in time. This *ex-post* calculation acknowledges that the quota utilized by the vessel may reflect not only the vessel owner's quota contribution to the cooperative, but also other cooperative member's quota that was fished by this vessel. However, given that most of the quota execution decisions are made prior to the season beginning this variable captures the total amount of crab quota they fished in each fishery. During the pre-BCRP era $Quota_{itf}$ was set equal to zero. The final variable utilized, $Strike_{tf}$ is a binary variable indicating whether or not the fishermen were striking due to failed price negotiations with the processors.[32] Strikes readily occurred during the pre-BCRP period within the snow crab fishery, but were not prevalent in the red king crab fishery. Therefore, this variable is not used in the probit regression for the red king crab fishery. The inclusion of the first, second and third order terms of PPR_{tf} captures the non-linear effect that inclement weather has on the captain's decision to fish or not on a given day.[33] The variable $no\_weather_{tf}$ is a dummy variable indicating whether or not the weather data was missing that day within a particular fishery.[34] The main equation estimated is,

$$\begin{aligned}\ln(\hat{V}_{itf}) = \lambda_0 + \lambda_1 \ln(ExpRvn_{itf}) + \lambda_2 USCG_{itf} + \lambda_3 BCRP_{itf} + \lambda_4 \ln(wave_{itf}) \\ + \lambda_5 \ln(PPR_{itf}) + \lambda_6 no\_weather_f + \rho\eta_{itf} + \nu_{itf}\end{aligned} \quad (3)$$

[32] We would like to thank the employees at the Alaska Department of Fish and Game's field office in Dutch Harbor, AK for providing this information.

[33] A cubic specification was selected following the empirical testing of the probit model under alternative specifications.

[34] We do not utilization the same data imputation method used for the vessel characteristics because we do not observe covariates that would facilitate the matching of "like" days within the data because if a day is missing than all the weather data is missing. Therefore, we have elected to utilize a dummy variable to capture this effect.

where all variables are as defined earlier except for η_{itf} which is the inverse mills ratio (IMR). The empirical results from the Heckman model are in Table 3. The top panel is the probit equation and the bottom panel is the main equation.

Parameter estimates for the determinants of a captain's decision to fish or not on a given day are contained in the upper panel of Table 3. With the exception of the coefficient on expected revenues within the red king crab fishery (to be explained in the upcoming section) the probit estimates yield a consistent behavioral profile within both fisheries. The probability a captain elects to fish on a given day increases in the post-USCG era, with the cumulative number of days fished and the remaining quota a vessel possesses. However, the second order term on the cumulative days fished indicates that the probability increases at a decreasing rate. The probability a captain elects to fish on a given day decreases in the post-BCRP era, if their next delivery is not upcoming, if there is inclement weather and if there is currently a price negotiation strike within the fishery. The coefficient on expected revenues in the snow crab fishery conforms to our *a priori* expectations as higher expected daily revenues increase the probability that they will fish. However, this is not true within the red king crab fishery. Upon closer inspection of the data within the red king crab fishery we discovered that for a majority of the observations the expected revenues in the previous time period are greater than the current time period, indicating that there is a propensity for the daily revenues to decrease within a season. This statistical phenomenon appears to be driving the negative coefficient and is consistent with recent research that indicates serial depletion may be present within this fishery (Schnier 2009). Presumably fishermen are still electing to fish on a given day because the revenues they expect to derive exceed the variable costs they will incur despite the lower catch-per-a-unit of effort that exists within the fishery.

The positive coefficient on the post-USCG period captures the "race for fish" that took place during this time period as the season lengths during this time period were shortening leading up to the BCRP. This effect is reversed following the inception of the BCRP as the "race for fish" was reduced with the introduction of LAPPs in these two fisheries. The negative and statistically significant coefficient on the post-BCRP period, captures one of the important features of the BCRP in that fishermen can be more flexible in their fishing time decisions and the fact that vessels often take multiple trips with a higher rate of intermediate down time than prior to the BCRP. Prior to the BCRP the probability mass that an individual fished on a given day was contained over a short time period (see Figure 2), whereas following the BCRP the probability mass is more spread out as the season length substantially increased. Therefore, *ceteris paribus* a fisherman was more likely to fish on a given day in the pre-BCRP than in the post-BCRP period. Another notable parameter estimate is the combined effect of inclement weather in both fisheries indicates that a captain is less likely to fish in inclement weather, *ceteris paribus*, which is consistent with the motivation of this research.

The estimates of equation 4, (Table 3, lower panel), indicate that our daily measure of the VSL is positively influenced by expected daily revenues in both fisheries. This result would be expected because if one holds the fatality risk rate constant and the economic returns per expected fatality are increasing, then so will the VSL. This result is consistent with the VSL literature on developing nations where it has been found that countries with higher earnings also possess a higher measure of the VSL (Bowland and Beghin 2001; Gibson et al. 2007). The two policy variables, USCG and the BCRP, have the same effect on the VSL in both fisheries. In the post-USCG era the VSL estimate was larger because during this time period the daily gross revenues received by the captain and crew was greater than in the post-BCRP period, which also explains the negative coefficient for the post-BCRP period. Given this information, if one holds the fatality risk constant the VSL would be higher in the post-USCG period and lower in the post-BCRP period which is consistent with our coefficient estimates. One other factor that increases the VSL in the post-USCG period, and also further exacerbates the decrease in the post-BCRP period, is the fact that the fatality risk rate substantially decreased following the USCG Pre-Season Boarding Program. The weather variables used to proxy for the degree of risk on a given day illustrate that wave height increases the VSL estimate within the red king crab fishery and decreases it within the snow crab fishery and that the PPR has a negative effect on the VSL in both fisheries. The negative effect of the PPR can readily be explained because it is highly correlated with the fatality risk rate. If the PPR increases so to does the fatality risk rate which, holding revenues constant, will decrease the VLS *ceteris paribus*. Finally, the statistically significant coefficient on the inverse mills ratio for both fisheries indicates that sample selection is an issue in our initial estimates of the VSL for both fisheries.

The sample selection corrected measure of the VSL, denoted $\bar{\bar{V}}^*$ in Table 3, are lower than our earlier estimates, which would be expected given the presence of our sample selection bias because our initial estimates of the VSL are an upper bound on the true underlying VSL. Our estimates of $\bar{\bar{V}}^*$ within the snow crab fishery purge bias from our baseline estimates of the VSL and indicate that the VSL is approximately \$4.76M, which is roughly 18% lower than our estimates of $\bar{\bar{V}}$ in this fishery. Within the red king crab fishery our estimates of $\bar{\bar{V}}^*$ are approximately \$4.00M, which is roughly 13% lower than our estimates $\bar{\bar{V}}$ in this fishery. In addition to our estimates of $\bar{\bar{V}}^*$ within these fisheries, which are averages across the population of participating fishermen, we also observe individual vessel-specific measures of the VSL as well. Figure 4 illustrates the vessel specific measures of non-sample selected corrected measures of the VSL, denoted V_i, and the sample selection corrected measures of the VSL, denoted V_i^*, sorted from the lowest measure of V_i to the highest for both fisheries. The sample selection model reduces high V_i estimates (right side of the Figure) and increases those estimates, which were too low (left side of the Figure). However, by and large, the V_i^* estimates predominately lie along our mean estimates of Table 3.

Heterogeneous VSL Estimation

Heterogeneity in fishing behavior has been well documented in the literature. Commercial fishermen exhibit heterogeneous spatial behavior (Smith 2005; Schnier 2009), production methods (Flores-Lagunes et al. 2007; Felthoven et al. in press), and risk perceptions (Mistean and Strand 2000). Given the prevalence of preference heterogeneity in commercial fisheries, especially with regard to risk preferences, it is plausible that there exists heterogeneity in the captain's willingness to substitute revenues for risk, and hence heterogeneous VSLs, within the two crab fisheries studied. This could be generated by either their misperceptions regarding the underlying risk (Viscusi 1990), or direct differences in their preferences, the latter manifesting itself in a heterogeneous marginal rates of substitution for risk and returns. Therefore, it is important that we consider latent heterogeneity within our analysis. Furthermore, it has recently been theoretically demonstrated that failing to control for heterogeneity in an agent's ability to deal with work-related risk will bias the VSL estimates upward (Shogren and Stamland 2002). Using a finite mixture model (Aitken and Rubin 1985; Swait 1994; MacLachlan and Peel 2000) to estimate V_{itf}, we will control for this form of latent heterogeneity in our analysis.

The finite mixture model generalizes our reduced form expression of the revenue equation function, Equation (1), by relaxing the assumption that β is a constant behavioral parameter across all fishermen. Instead we estimate $j = 1,...,J$ different segment-specific behavioral parameters, denoted $\beta_{0|j},...,\beta_{8|j}$. We also estimate the probability that the behavior of fisherman i participating in fishery f is represented by the j^{th} set of coefficients, denoted P_{ijf}, $j = 1,..,J$. Assuming a standard logit probability function, we have

$$P_{ijf} = \frac{\exp(Z_{if}\gamma_j)}{\sum_{l=1}^{J}\exp(Z_{if}\gamma_l)}, \tag{4}$$

with fishermen-specific observation matrices, Z_{if}, and segment-specific participation coefficients, γ_j. Given the high degree of heterogeneity in the vessel characteristics, we include two measures of vessel-specific capital structure, the vessel's net tonnage and hold capacity, in Z_{if}. In addition, we include a segment-specific constant and a variable indicating whether or not a vessel fished in the post-BCRP time period, denoted $VesRat_{if}$. This last variable will serve to proxy for the latent ability of fishermen to cope with the risks present within the BSAI. Vessels which fished in the post-BCRP period likely did so because they were the most efficient vessels and, in turn, could afford to pay other vessels for the right to land their quota. Although production efficiency would increase the probability that a vessel fished rather than leasing their quota to the cooperative and sitting idle, its ability to cope with the risks in the fishery would presumably also increase their probability of being selected. A vessel which is more stable in bad weather and better suited to cope with the prevailing weather conditions will be more desirable to fish than one which is unstable. Given the probability statement in Equation (4) the full likelihood function for Equation (1) with heterogeneous vessels is,

$$L_f = \prod_{i=1}^{N}\prod_{t=1}^{T_i}\prod_{j=1}^{J} P_{ijf} R(X_{itf};\beta_{f|j}) \tag{5}$$

where T_i denotes total daily observations for fishermen i, N is the total number of fishermen in the dataset, and $R(X_{itf};\beta_{f|j})$ is the revenue function in Equation (1) with parameters $\beta_{f|j} = \beta_{0f|j},....,\beta_{8f|j}$ substituted for $\beta_{f0},...,\beta_{f8}$. To determine the appropriate number of segments to use in the finite mixture model the Bayesian Information Criterion and corrected Akaike Information Criterion were used (MacLachlan and Peel 2000). These tests were conducted by first estimating the $J=1$ (homogenous β) model and then increasing the number of segments until the test statistics unilaterally indicated that the previous number of segments was the best. The test results are in Table 4. Although test statistics indicate that the $J=3$ is preferred to the $J=2$ model within both fisheries, we elected to stop at $J=2$ for both fisheries because the model suffered from a high degree of multicolinearity when $J=3$ and the results created segments with near zero probability, degenerating to two-segment models.[35]

[35] For both fisheries we were unable to obtain reliable estimates when we assumed J=3 because both models generated a third segment with extremely low probabilities of participation for each vessel (less than 0.00001 for all vessels) which made it impossible to invert the hessian and obtain reliable parameter estimates. In essence, the J=3 model was degenerating to a J=2 model. This also further supported our decision to stop at J=2 in the analysis.

Given the multi-stage nature of our empirical model we estimate the finite mixture regression for only Equation (1) (after instrumenting fatality rates). Equation (1) is the most important stage of the model because it determines the upper bound on our estimates of the VSL and is the obvious place to control for vessel heterogeneity. The sample selection portion of the model is used to uncover the true underlying VSL and is therefore preserved except for one aspect of the model. In Equation (4) the constant is broken down into the respective segments by using the probability of segment participation predicted by our parameter estimates in Equation (5) as independent variables in the model.

The finite mixture model results for the red king crab and snow crab fisheries are in Tables 5 and 6 respectively. For both fisheries, the segment participation probabilities have been normalized on segment one, therefore we do not report parameter estimates for $j = 1$. Within the red king crab fishery the baseline probability that a vessel exhibits behavior consistent with segment two is substantially below that for segment one, as captured by the constant term, but it is increasing with a vessel's hold capacity. Furthermore, one's participation in the fishery following the BCRP, nor a vessel's net tonnage has any discernable impact on the probability of being in segment two. Within the snow crab fishery the baseline probability of being in segment two, as captured by the constant, is greater than that for segment one. In addition, one's participation in the fishery following the BCRP increases their probability of being in segment two whereas their fixed inputs (net tonnage and hold capacity) have no impact on their segment participation probability. One important feature of the finite mixture model is that it does not precisely partition the vessels into either segment one or two. Instead, each vessel i possesses an estimated probability of being in both segments, $\hat{P}_{i|f}$ and $\hat{P}_{i2f}$ respectively. The vessel specific behavioral parameters can be recovered by multiplying their vessel specific segment probabilities by the estimated behavioral parameter and summing over the segments. This allows us to recover vessel specific measures of the marginal rate of substitution for risk and returns within both fisheries. Each vessels marginal rate of substitution was calculated as follows,

$$MRS_{if} = \sum_{j=1}^{J} \hat{P}_{ijf} \hat{\beta}_{8f|j}, \qquad (6)$$

which is used to estimate the vessel-specific, finite mixture (FM) measures of $\hat{V}_{itf}^{FM}$, the dependent variable in the sample selection model of Equation (4). Figure 5 illustrates the finite mixture model estimates of MRS_{if}. From this figure it is evident that the homogeneous model, $(J = 1)$, under-estimates the marginal rate of substitution within the red king crab fishery and overestimates it within the snow crab fishery.

Parameter estimates for segment one within both the red king crab fishery and segment two within the snow crab fisheries are consistent with those observed when we assume homogeneous preferences, $(J=1)$, contained in Table 4. The parameter estimates for segment two in the red king crab fishery indicate that the daily revenues for vessels with a higher probability of being in segment two are more positively impacted by the price of crab and the length of their vessel and are more negatively impacted by their hold capacity and their activity in the post-USCG period than the segment one vessels. Within the snow crab fishery the results indicate vessels with a higher probability of participation in segment 1 are more positively influenced by their mobility (horsepower) as well as their participation in the post-BCRP period and the available stock than vessels in segment two. These vessels also are less impacted by the price of crab and have a much lower MRS for fatalities than those vessels within segment two. This said, it is important to note that the true parameter for each vessel is the mixture of the two segments (see Equation (6)). Furthermore, despite the negative and statistically significant coefficient on fatalities within the snow crab fishery the segment participation probabilities are low enough that the vessel-specific MRS are never negative. In fact they never fall below 0.118 within the analysis (see Figure 4).

The variable of primary interest is the vessel-specific measure of the marginal rate of substitution. Given the differences in our estimates of MRS_{if} across the segments in both fisheries, we would expect our estimates of the VSL in the red king crab fishery to increase relative to the homogeneous model, $(J=1)$, and decrease within the snow crab fishery. This is precisely what we observe. The finite mixture (FM) estimates of $\overline{\overline{V}}$, denoted $\overline{\overline{V}}^{FM}$ in Tables 5 and 6, are 6% greater than those in Table 2 for the red king crab fishery ($4.87M) and 11% less within the snow crab fishery ($5.14M). This indicates that our initial estimates within the red king crab fishery was biased downward and those within the snow crab fishery were biased upward. Furthermore, these results persist when we correct for sample selection, resulting in our VSL estimate denoted $\overline{\overline{V}}^{FM*}$ in Table 7 of $4.21M and $4.19M for the red king crab and snow crab fisheries respectively.

These finite mixture results suggest that there is a bias when assuming a homogeneous preference model, $J=1$, relative to a model in which we account for latent agent-specific heterogeneity. However, only the biases observed in the snow crab fishery are consistent with Shogren and Stamland's (2002) theoretical result that ignoring heterogeneity will bias our estimates of the VSL upward, whereas in the red king crab fishery ignoring heterogeneity biases them downward. However, the 5% downward bias in the red king crab fishery is relatively small, compared to the 12% upward bias within the snow crab fishery. This said, our notion of heterogeneity does not perfectly correlate with Shogren and Stamland's argument, which may explain the difference. Although further elaboration is beyond the scope of this research, future research on this form of heterogeneity may benefit from using Shogren and Stamland's GMM estimation algorithm to control for heterogeneity (Shogren and Stamland 2006).

Intra-Vessel Comparison of V_i^*

Estimating a vessel- and fishery-specific VSL allows us to conduct an intra-vessel comparison of their estimated V_{if}^* across fisheries. To the best of our knowledge this type of analysis has never been conducted. This is most likely due to fact that conducting an intra-population comparison within the general labor market requires tracking an individual as they move from one occupation to another and then estimating the implied VSL in both environments, controlling for all other factors that may contribute to their occupational decisions. This would be inherently problematic and subject to an omitted variable bias, because one would have to control for changes in a workers' life stages which may be very difficult. In our sample, this is not an issue because for a sub-sample of the vessels in our data we directly observe them fishing in one fishery and only a few months later (almost contemporaneously) fishing in the other. Furthermore, the switching between fisheries occurs repeatedly over the time period studied. Comparing our vessel specific estimates of $\overline{\overline{V}}_i^{FM*}$, across both fisheries allows us to investigate whether or not the implicit tradeoffs these fishermen are making are constant across fisheries (occupations).

There are 264 vessels that participated in both the red king crab and snow crab fisheries within our data. Figure 6 illustrates the mean vessel-specific VSL estimates for both fisheries as well as 95% confidence intervals with the vessels ordered from the lowest to highest VSL measures in the red king crab fishery. The 95% confidence intervals were constructed by calculating the vessel-specific standard deviations of their daily VSL estimates within both fisheries. The average percentage difference between the vessel-specific VSL estimates in the red king crab fishery from their VSL estimate within the snow crab fishery is approximately -70%, but if the top 10% of the deviations are removed the average reduces to 6%. Furthermore, conducting a *t-test* of distributional equivalence at the vessel level indicates that for roughly 92% of the vessels their two measures of the VSL are not statistically different from each other.[36]

[36] The percentage was calculated by constructing a vessel-specific *t-stat* (taking the mean vessel-specific VSL in the red king crab fishery, subtracting the mean in the snow crab fishery and then dividing by the standard deviations in

These results are remarkable and novel, because the average daily revenues within the snow crab fishery are roughly half of those in the red king crab fishery and the daily fatality risk rates are substantially higher due to the time period in which this fishery is executed. Both of these factors would generate a lower VSL estimate in the snow crab fishery were the marginal rate of substitution constant across both fisheries. However, the differences in the marginal rates of substitution correct for this difference in the earnings-risk ratio and generate a similar profile of intra-vessel VSL estimates. This indicates that the behavior of captains is consistent across the two risk-return profiles, providing the first ever intra-agent test of VSL stability.

Focusing on the total population, the mean absolute dollar difference in the vessel-specific VSL estimates between the red king crab and snow crab fisheries (including both positive and negative deviations) was roughly \$2.15M, which further illustrates the consistency in their behavior given that average daily standard deviation in the VSL was \$2.30M in the red king crab fishery and \$2.22M in the snow crab fishery for the 264 vessels that participated in both fisheries. However, these standard deviations do highlight the fact that our estimates contained in Tables 2-7 are population averages of individual averages. The full range of our VSL estimates contains a roughly \$2M upper and lower bound confidence interval on our estimates. This suggests that our estimates range anywhere from slightly over \$2M to slightly over \$6M across all vessels and days within the data set.

IV. Conclusion

This research estimates the VSL for one of the riskiest occupations, which has recently been popularized as "The Deadliest Catch" by the Discovery Channel's reality TV show. Using two recent policy changes within the BSAI crab fisheries as well as weather data, we instrument for the endogenous daily risk present and investigate the structural breaks in the risk profile resulting from these policies. Our estimates of the VSL range from \$4.00M to \$4.76M depending on the modeling assumptions and fishery studied. These estimates control for the inherent sample selection bias present in many VSL estimates and, when compared to those estimates which do not control for sample selection, illustrate the substantially upward biases which may arise (Ashenfelter 2006). In addition, these estimates are robust to heterogeneous preferences that bias our homogeneous estimates of the VSL in both fisheries, but in opposite directions. Conducting an intra-agent analysis of our VSL across the two fisheries studied illustrates that our estimates are remarkably stable and not statistically significant from one another for roughly 92% of the population. Combined, this analysis conducts the first contemporary risk-return trade

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the red king crab fishery) and then determining what percentage had a *t-stat* less than 1.96. Reversing the VSL ordering yields a statistic of 88%.

off study of agent behavior in a high-risk natural resource extraction industry as well as the first intra-agent comparison of VSL estimates.

More generally these results illustrate that fishermen participating in the Alaskan crab fisheries make strikingly similar decision to those observed by the greater population. This suggests that these fishermen are no more risk-loving than the average decision maker traditionally modeled in the VSL literature because the risk premium they receive for incurring the physical risks they incur is consistent with that observed in the general population. Although more research is required to confirm this conjecture, it does correspond with our perception of the fishermen we interviewed while conducting this research. Furthermore, these estimates may be used to benefit contemporary fisheries policy. For instance, recently the New York Times reported that the fatality rates within the Pacific Northwest dungeness crab fisheries possessed fatality risk rates that were 60 times greater than the average American worker (Bakalar 2008). As a result of this, managers are looking into the option of increasing the coverage of their vessel safety inspections to decrease the fatalities observed in this fishery. Our estimates of the VSL could be used to evaluate the efficacy of this policy. For instance, the USCG program was conducted using existing staff members in Dutch Harbor, minimizing the marginal cost of program. Given the large reduction in fatalities that resulted from this program our results validate the economic efficacy of this program. In our future research we anticipate investigating the asymmetry in the biases associated ignoring heterogeneous preferences within these two fisheries as well as exploring other unique features of the data set that we believe will further forward our knowledge of risk behavior within this environment as well as expanding our analysis to help inform future fisheries policy.

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Figures and Tables

Table 1. Descriptive Statistics by fishery ($'s converted to 2007$'s). Years used in calculation contained in parantheses.

	Red King Crab Fishery			
	Pre-Rationalization (97-04)		**Post-Rationalization (05-07)**	
Variable	Mean	Standard Dev.	Mean	Standard Dev.
Annual Revenues[a]	248,193.70	169,752.95	865,883.40	621,061.04
Daily Earnings[b]	13,307.09	9,469.59	9,330.87	4.981.13
Trip Len. (days)[a]	6.71	0.98	10.84	5.89
Total Lbs. (yr.)	45,655.63	30,399.05	201,604.40	141,747.02
Vessel Length	114.17	26.99	116.27	21.98
Hold Cap. (lbs.)	7,958.61	7,288.71	8,007.63	6,088.53
Net-tonnage	148.71	103.07	153.01	107.96
Horsepower	1,034.06	580.98	1,049.43	472.80
Crew members	5.05	0.85	5.07	0.93

	Snow Crab Fishery			
	Pre-Rationalization (97-05)		**Post-Rationalization (06-07)**	
Variable	Mean	Standard Dev.	Mean	Standard Dev.
Annual Revenues[a,c]	426,346.77	348,874.31	614,807.64	451,374.27
Daily Earnings[b]	5,711.56	3,988.94	4,716.25	2,888.23
Trip Len. (days)[a]	15.21	10.91	13.18	6.35
Total Lbs. (yr.)[c]	362,164.78	415,734.18	441,270.64	304,185.28
Vessel Length	115.94	26.98	119.86	22.12
Hold Cap. (lbs.)	8,223.76[d]	7,627.33	8,502.64	6,651.64
Net-tonnage	152.42	107.89	158.04	116.53
Horsepower	1,014.66	566.96	1,058.88	358.28
Crew members	5.22	0.89	5.32	1.05

[a]Annual revenues are the gross reported revenues within the fish ticket database. [b]Daily earnings are the portion revenues paid to the captain and crew and calculated using the methods described in Appendix A.1. [c]The annual revenues and total pounds landed include the pre-2000 time period during which the TAC was substantially larger than in the post-2000 time period. The higher TAC substantially increased the average annual revenues and annual landings during this time period.

Table 2: Regression estimates of $\ln(R_{itf})$.

Parameters	Red King Crab Fishery	Snow Crab Fishery
β_0 $(const)$	1.6316** (0.22)	1.7797** (0.11)
β_1 $\ln(price)$	0.2620** (0.04)	0.6186** (0.02)
β_2 $\ln(length)$	0.8717** (0.04)	0.5440** (0.02)
β_3 $\ln(hp)$	0.0515** (0.02)	0.2617** (0.01)
β_4 $\ln(hold)$	0.0754** (0.01)	0.1033** (0.01)
β_5 $(USCG)$	0.5638** (0.04)	-0.0627** (0.02)
β_6 $(BCRP)$	-0.0903 (0.10)	0.7606** (0.05)
β_7 $\ln(GHL)$	0.2466** (0.09)	0.9032** (0.05)
β_8 $\ln(fatal^{IV})$	0.0691** (0.02)	0.1446** (0.01)
$\overline{\overline{V}}$	$4.59M	$5.78M
N	17,733	52,798
$\log(L(0))$	-40,633.15	-101,804.54
$\log(L)$	-17,108.34	-50,819.17

(** indicates statistical significance at the 95% level; log(L(0)) is the log-likelihood when the parameter vector is set equal to zero.)

Table 3: Sample Selection Estimation of V^*

Selection Equation		
Parameter	**Red King Crab Fishery**	**Snow Crab Fishery**
ω_0 $\cancel{\omega_0}$	0.1864**	0.0588**
	(0.02)	(0.02)
ω_1 $(ExpRvn)$	-0.0028**	0.0020**
$\cancel{\omega_1\ (ExpRvn)}$	(0.00)	(0.00)
ω_2 $(USCG)$	0.0973**	0.4690**
$\cancel{\omega_2\ (USCG)}$	(0.03)	(0.02)
ω_3 $(BCRP)$	-4.2297**	-2.5573**
$\cancel{\omega_3\ (BCRP)}$	(0.05)	(0.02)
ω_4 $(days)$	0.2833**	0.0789**
$\cancel{\omega_4\ (days)}$	(0.01)	(0.01)
$\omega_5(days^2)$	-0.0052**	-0.0013**
	(0.00)	(0.00)
$\omega_6(del)$	-0.0373**	-0.0735**
	(0.00)	(0.00)
$\omega_7(Quota)$	4.7095**	3.2036**
$\cancel{\omega_6\ (Quota)}$	(0.08)	(0.05)
$\omega_8(Strike)$	-------	-2.0391**
$\cancel{\omega_7\ (Strike)}$		(0.03)
ω_9 $(no\_weather)$	-0.0221	-0.2498**
	(0.04)	(0.03)
$\omega_{10}(PPR)$	-0.9400**	-0.0278**
	(0.25)	(0.00)
$\omega_{11}(PPR^2)$	0.2108**	0.0015**
	(0.08)	(0.00)
$\omega_{12}(PPR^3)$	-0.0123**	-0.0001**
	(0.01)	(0.00)
N $\cancel{N}$	32,784	93,675
$pseudo-R^2$ $\cancel{LL}$	0.3039	0.3944

(** indicates statistical significance at the 95% level, * indicates statistical significance at the 90% level.)

Table 3(cont): Main Equation

Main Equation		
Parameter	**Red King Crab Fishery**	**Snow Crab Fishery**
λ_0 $(const)$	4.9848**	7.6851**
$\cancel{\lambda_0 \ (const)}$	(0.07)	(0.04)
λ_1 $(ExpRvn)$	0.8889**	0.7995**
$\cancel{\lambda_1 \ (ExpRvn)}$	(0.01)	(0.00)
λ_2 $(USCG)$	1.2239**	0.4795**
$\cancel{\lambda_2 \ (USCG)}$	(0.01)	(0.01)
λ_3 $(BCRP)$	-0.0404**	-0.4691**
$\cancel{\lambda_3 \ (BCRP)}$	(0.01)	(0.01)
λ_4 $(wave)$	0.0415**	-0.0028**
$\cancel{\lambda_4 \ (wave)}$	(0.01)	(0.00)
λ_5 (PPR) $\cancel{\lambda_5 \ (PPR)}$	-0.1602**	-0.1480**
	(0.06)	(0.00)
λ_6 $(no\_weather)$	-0.2985**	-0.0940**
$\cancel{\lambda_6 \ (no\_weather)}$	(0.02)	(0.01)
ρ (IMR) $\cancel{\rho\sigma \ (IMR)}$	0.0772**	0.2037**
	(0.01)	(0.01)
$\bar{\bar{V}}^*$ $\cancel{\bar{\bar{V}}^*}$	\$4.00M	\$4.76M
N $\cancel{N}$	17,788	52,798
$\log(L(0))$	-73,341.29	-218,963.20
$\log(L)$ $\cancel{LL}$	-13,043.42	-44,728.95

(** indicates statistical significance at the 95% level, * indicates statistical significance at the 90% level, log(L(0)) is the log-likelihood when the parameter vector is set equal to zero.)

Table 4: Finite Mixture Model Specification Tests

Model	**Red King Crab**		**Snow Crab Fishery**	
	BIC	**crAIC**	**BIC**	**crAIC**
$J=1$	34,304.73	34,234.69	101,736.21	101,656.34
$J=2$	32,820.97	32,649.80	97,170.75	96,975.54
$J=3^a$	32,186.51	31,914.08	96,445.28	96,134.73

([a]As discussed in the paper, for both fisheries the log likelihood used for *J=3* resulted from a model that degenerated to a two-segment model due to multicolinearity in the parameter estimates. Therefore, although the BIC and crAIC indicate that *J=3* is superior to *J=2* we have elected to utilize only the *J=2* parameter estimates within the analysis. Further details on this estimation issue can be obtained from the authors.)

Table 5: Finite Mixture Results for the Red King Crab fishery

Segment Participation Variables		
Parameter	**Segment 1**	**Segment 2**
γ_0 $(const)$	-------	-4.2794**
		(0.23)
γ_1 $(VesRat)$	-------	-0.2448
		(0.21)
γ_2 (net_tons)	-------	0.5686
		(0.67)
γ_3 $(hold)$	-------	0.0267**
		(0.01)
Segment Estimates of V		
$\beta_{0\|j}$ $(const)$	1.7585**	-6.9537
	(0.29)	(4.98)
$\beta_{1\|j}$ $\ln(price)$	0.1661**	4.9569**
	(0.05)	(1.01)
$\beta_{2\|j}$ $\ln(length)$	0.8268**	1.9742**
	(0.06)	(0.67)
$\beta_{3\|j}$ $\ln(hp)$	0.0214	0.4577
	(0.03)	(0.34)
$\beta_{4\|j}$ $\ln(hold)$	0.1097**	-0.6119**
	(0.01)	(0.22)
$\beta_{5\|j}$ $(USCG)$	0.6110**	-1.8843**
	(0.04)	(0.89)
$\beta_{6\|j}$ $(BCRP)$	-0.0918**	-1.3037
	(0.16)	(2.30)
$\beta_{7\|j}$ $\ln(GHL)$	0.2445**	-1.0173
	(0.14)	(2.16)
$\beta_{8\|j}$ $\ln(fatal^{IV})$	0.0745**	-0.3914
	(0.02)	(0.48)
$\overline{\overline{V}}^{FM}$	$4.87M[a]	
N	17,733	
$\log(L(0))$	-40,633.15	
$\log(L)$	-16,302.87	

(** indicates statistical significance at the 95% level. [a] The VSL measures was calculated by setting the coefficient on fatalities equal to zero for segment 2 because it was not statistically significant; log(L(0)) is the log-likelihood when the parameter vector is set equal to zero.).

Table 6: Finite Mixture Results for the Snow Crab fishery

Segment Participation Variables		
Parameter	**Segment 1**	**Segment 2**
γ_0 $(const)$	-------	2.9994**
		(0.15)
γ_1 $(VesRat)$	-------	1.1054**
		(0.11)
γ_2 (net_tons)	-------	0.9313
		(0.60)
γ_3 $(hold)$	-------	-0.0041
		(0.01)
Segment Estimates of V		
$\beta_{0\|j}$ $(const)$	-5.9475**	1.8350**
	(1.22)	(0.12)
$\beta_{1\|j}$ $\ln(price)$	-0.5101**	0.6017**
	(0.19)	(0.02)
$\beta_{2\|j}$ $\ln(length)$	0.5084*	0.5260**
	(0.27)	(0.02)
$\beta_{3\|j}$ $\ln(hp)$	0.5688**	0.2490**
	(0.13)	(0.01)
$\beta_{4\|j}$ $\ln(hold)$	0.0948	0.1068**
	(0.08)	(0.01)
$\beta_{5\|j}$ $(USCG)$	-0.1855	-0.0074
	(0.20)	(0.02)
$\beta_{6\|j}$ $(BCRP)$	3.6890**	0.6820**
	(0.53)	(0.06)
$\beta_{7\|j}$ $\ln(GHL)$	4.7213**	0.8372**
	(0.57)	(0.06)
$\beta_{8\|j}$ $\ln(fatal^{IV})$	-0.3534**	0.1443**
	(0.13)	(0.01)
$\bar{\bar{V}}^{FM}$	$5.14M	
N	52,798	
$\log(L(0))$	-101,804.54	
$\log(L)$	-48,465.76	

(** indicates statistical significance at the 95% level, log(L(0)) is the log-likelihood when the parameter vector is set equal to zero.)

Table 7: Main Equation Estimation for the Finite Mixture Model

Parameter	Red King Crab Fishery	Snow Crab Fishery
$\Pr(Seg=1)$	-1.0133	7.9254**
	(0.78)	(0.05)
$\Pr(Seg=2)$	4.9156**	1.1484**
	(0.07)	(0.17)
λ_1 $(ExpRvn)$	0.9017**	0.7840**
	(0.00)	(0.00)
λ_2 $(USCG)$	1.2076**	0.4820**
	(0.01)	(0.01)
λ_3 $(BCRP)$	-0.0221**	-0.5163**
	(0.01)	(0.01)
λ_4 $(wave)$	0.1235**	-0.0018
	(0.01)	(0.00)
λ_5 (PPR)	-0.2021**	-0.1480**
	(0.04)	(0.00)
λ_6 $(no\_weather)$	0.3345**	-0.0974**
	(0.10)	(0.01)
ρ (IMR)	0.0743**	0.2034**
	(0.01)	(0.01)
$\overline{\overline{V}}^{FM*}$	$4.21M	$4.19M
N	17,740	52,798
$\log(L(0))$	-73,341.29	-218,963.20
$\log(L)$	-13,145.08	-44,604.93

(** indicates statistical significance at the 95% level; *indicates statistical significance at the 90% level, log(L(0)) is the log-likelihood when the parameter vector is set equal to zero.)

Figure 1: Annual Fatality Rates per a 100,000 full-time equivalences (FTEs) in all of Alaska and the Alaskan Crab Fisheries. (source data obtained from Jennifer Lincoln, NIOSH – Alaska Field Station) – Alaska State crab fishery fatalities were removed because they were not rationalized, with BV indicates that Big Valley is included in the statistic and without BV indicates it has been removed.

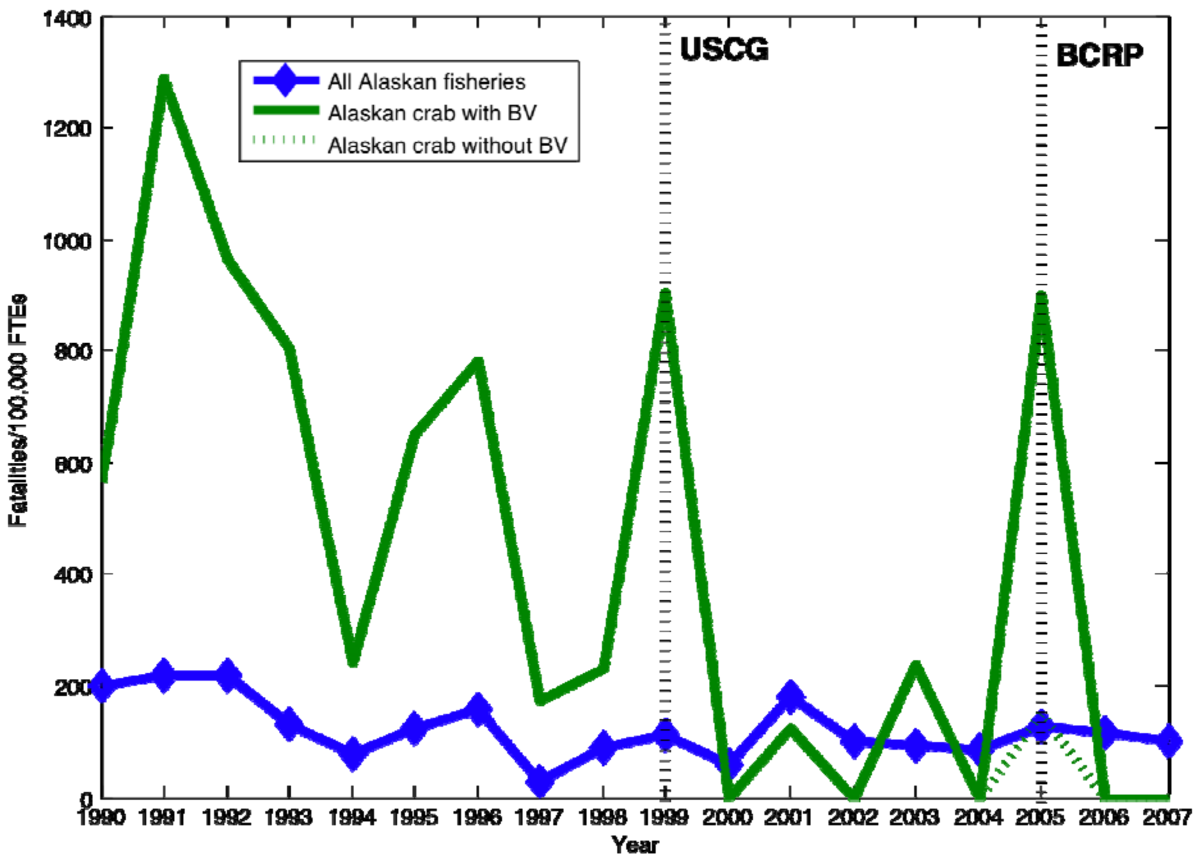


Figure 2: Number of fishing vessels (solid line) and season length (line with diamonds) by year and fishery. The USCG and BCRP lines represent the first years in which the policies took effect for each fishery.

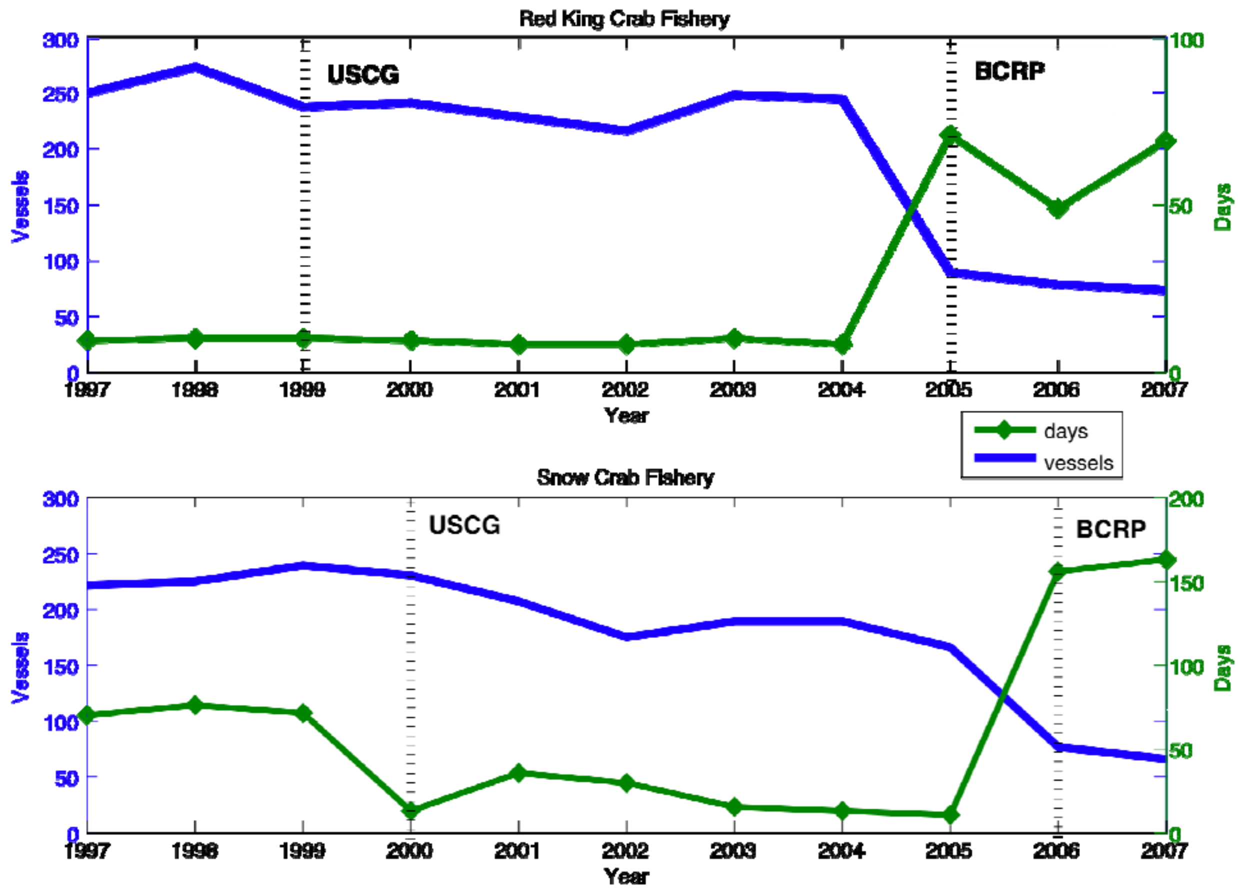


Figure 3: Full-time equivalence employment rates by year and fishery.

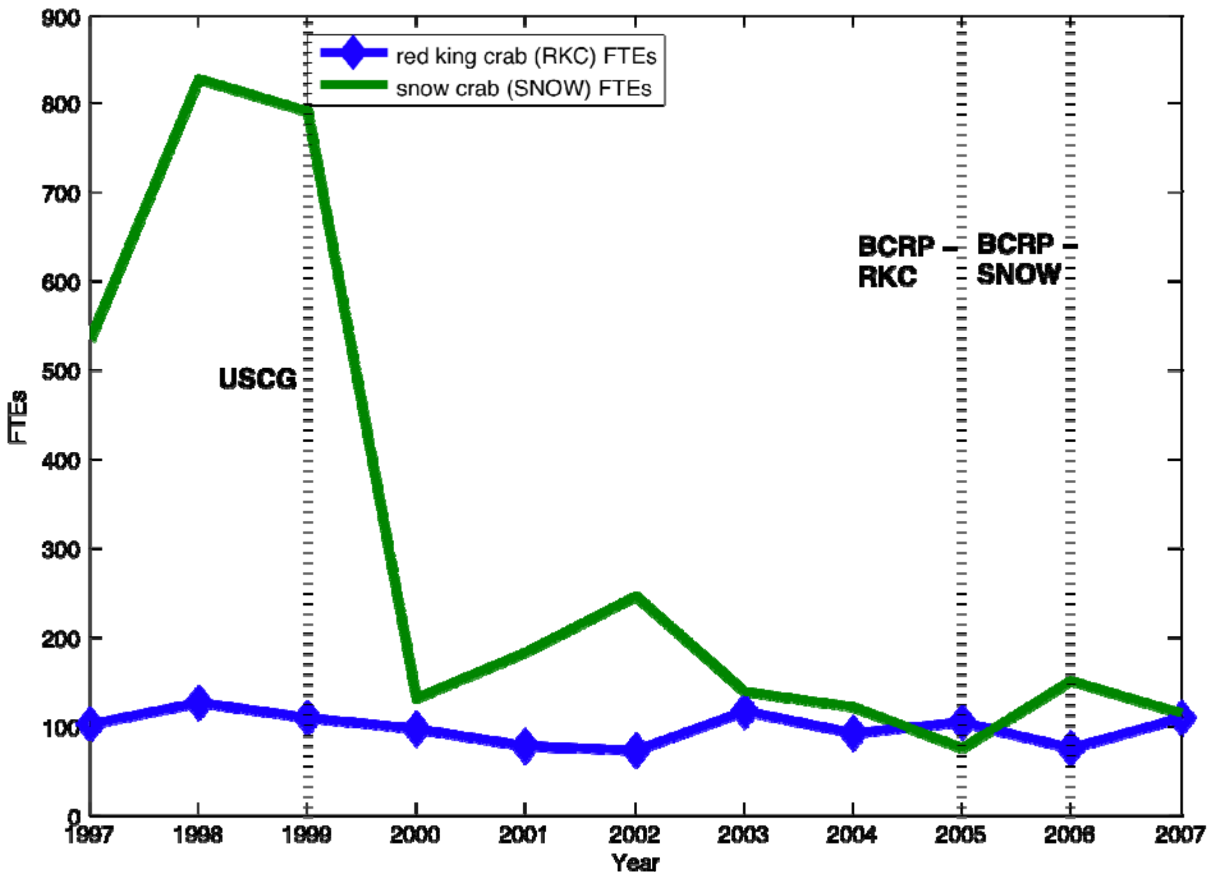


Figure 4: Mean vessel specific VSL estimates prior to sample selection correction V_i and following sample selection correction V_i^* in the red king crab and snow crab fishery respectively. Estimates are ordered from the lowest to highest vessel-specific estimates of V_i.

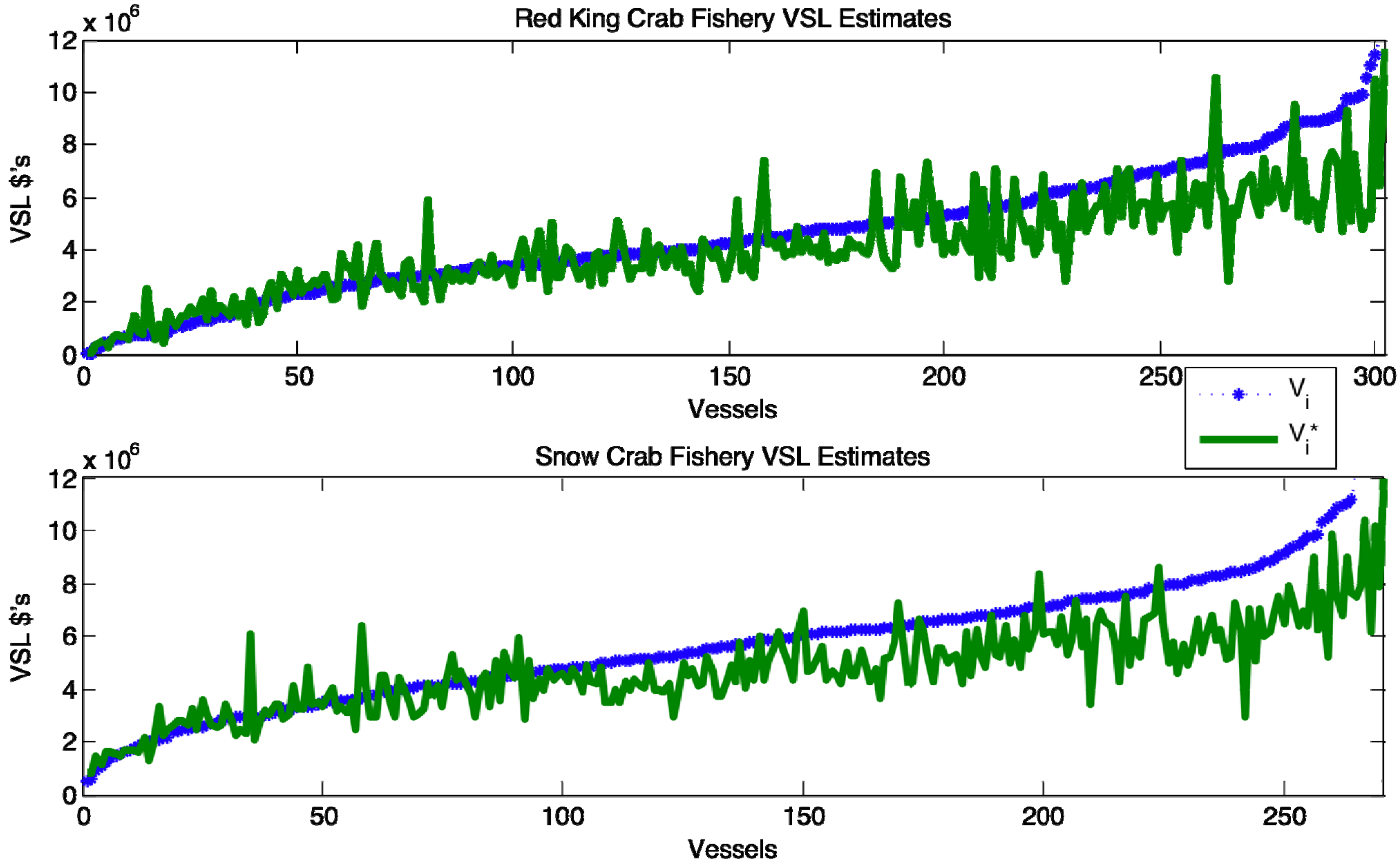


Figure 5: Finite Mixture estimates of the marginal rate of substitution (MRS) for earnings and risk, MRS_{if}, ordered from lowest to highest observed MRS.

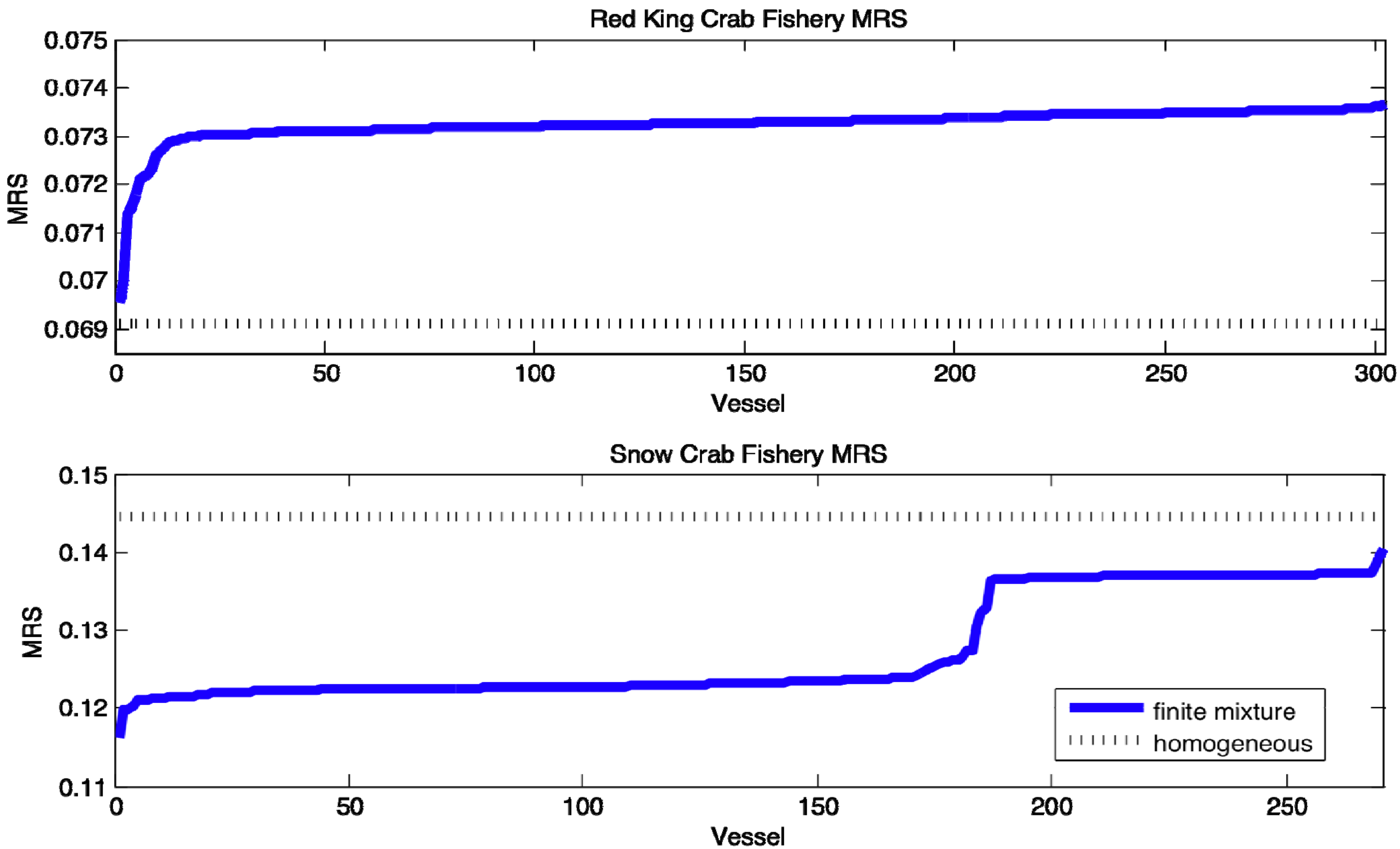
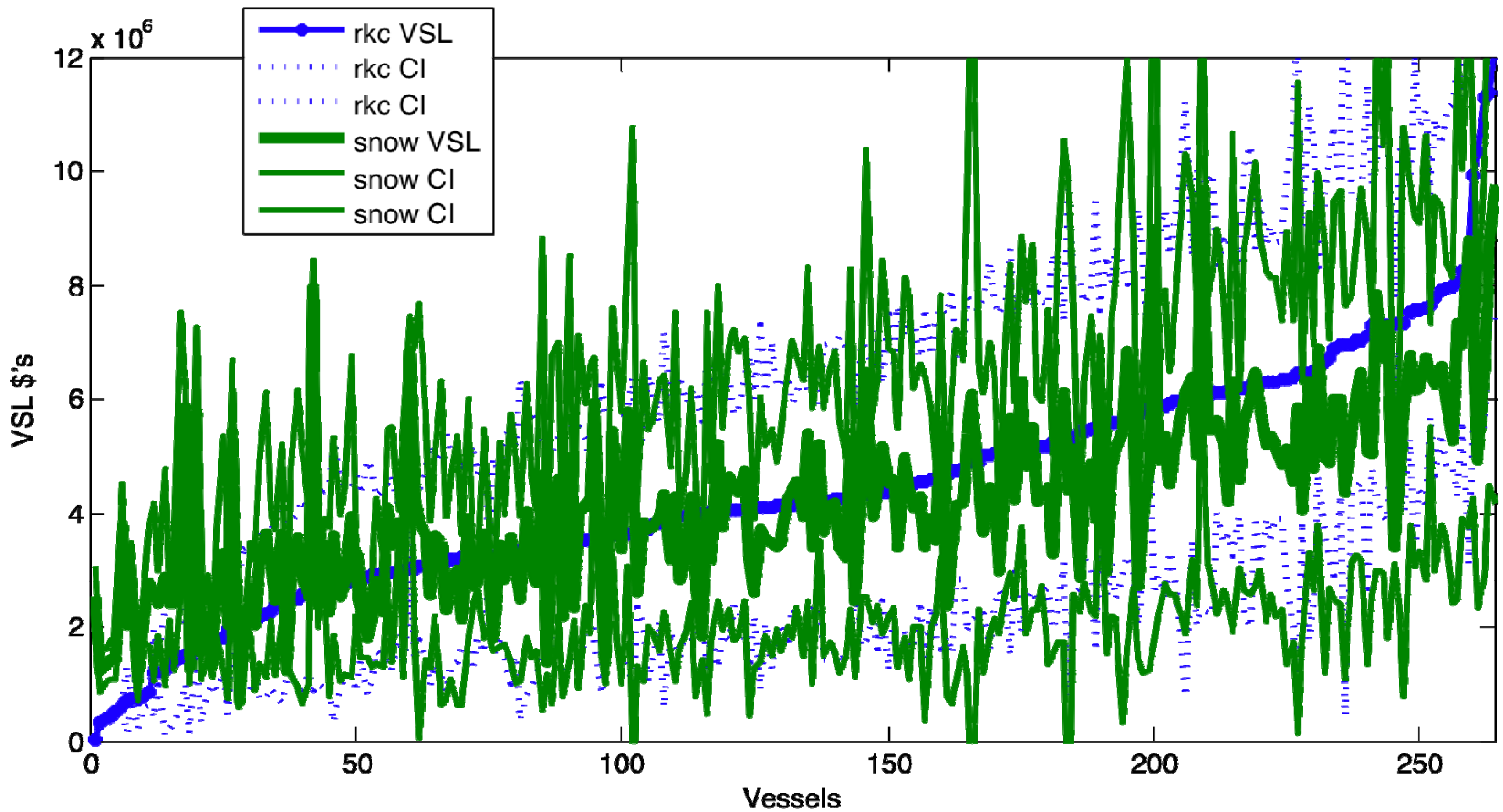


Figure 6: Intra-vessel comparison of the VSL estimates using the finite mixture results. Data ordered from lowest VSL in the red king crab fishery to the highest VSL estimated: rkc – denotes red king crab fishery; rkc CI – denote 95% confidence interval on the vessel-specific VSL estimates in the red king crab fishery; snow – denotes snow crab fishery; snow CI – denotes 95% confidence interval on the vessel-specific VSL estimates in the snow crab fishery.



Appendix – Sections A.1 and A.2

Section A.1:

Listed below are the variables used in the econometric models with their data source(s) indicated and additional information provided where applicable. All of the data is confidential, as required under the Magnuson-Stevens Fisheries Conservation Management Act, and was obtained from the National Marine Fisheries Service for this research.

R_{itf}: Mean revenues earned by the captain and crew on vessel *i*, day *t* and within fishery *f*. Data was obtained from the Alaska Department of Fish and Game (ADF&G) fish ticket database for both the pre and post-BCRP time periods. The fish tickets indicate the date fishing began, the date fishing ended, and the gross revenues earned. Because some of the fish tickets contained overlapping dates, some "trips" were constructed using the dates covered by the union of two or more fish tickets. To derive the daily revenues earned by crew we used a consistent approach that utilized the best source of data available. For the pre-rationalization years 1998, 2001, and 2004 we have direct observations on captain and crew earnings by fishery, which can be combined with gross revenue data to derive estimates of the percent of gross earnings paid to captain and crew on each trip. We applied these vessel-specific percentages to the other pre-rationalization years for which no EDR were available to impute estimates of revenues earned by captain and crew on each trip. For the post-rationalization years we had direct reports of the revenues earned by captain and crew in each fishery in all years, and these data were used in an analogous manner to derive trip-level daily earnings, R_{itf}. We should point out that we imputed captain and crew earnings in the pre- and post-BCRP periods separately because crew remuneration substantially changed following the BCRP; for many vessels the share of gross earnings going to crew decreased because much of the gross earnings were generated by, and used to pay for, additional quota purchased by the vessel (whose costs are typically shared among the vessel owner, captain, and crew). In addition, trip lengths in the years following the BCRP were longer and for a number of trips we used data from the vessel monitoring systems (VMSs) that were recently (2005-present) placed on these vessels to confirm trip lengths whenever the length exceed 18 days.[37] If it was deemed that a vessel had returned to port to during this time period the day was treated as non-fishing day. This verification was conducted on 47 trips in the red king crab fishery and 77 trips in the snow crab fishery during the post-BCRP period. In addition, all revenues were scaled up to 2007 dollars using the Consumer Price Index (CPI).

[37] 18 days was selected after consulting fishery experts and plotting a histogram of trip length which indicated that very few fishing trips exceeded 18 days.

$price_{itf}$: The per pound price of landed crab. This was obtained from the ADF&G fish ticket database. In addition, all prices were scaled up to 2007 dollars using the CPI.

$length_i$: The individual length of a given vessel. This was obtained from the ADF&G Commercial Fisheries Entry Commission (CFEC) vessel registration files.

hp_i: A vessels engine horsepower. This was obtained from the ADF&G CFEC vessel registration files.

$hold_i$: A vessel's live hold capacity. This was obtained from the ADF&G vessel registration files.

$gross\_ton_i$: A vessel's gross-registered tonnage. This was obtained from the ADF&G vessel registration files.

$USCG_{tf}$: A dummy variable indicating whether or not the United States Pre-Season Boarding Program was in effect: 1 indicates it was present and 0 not in present. In the red king crab fishery this began in 1999 and in the snow crab fishery it began in 2000.

$BCRP_{tf}$: A dummy variable indicating whether or not the Bering Sea Crab Rationalization Program was in effect: 1 indicates it was present and 0 not present. In the red king crab fishery this began in 2005 and in the snow crab fishery it began in 2006.

GHL_{tf}: The gross-harvest limit imposed on each fishery. Data was obtained from the Stock Assessment and Fishery Evaluation (SAFE) Report, compiled by the Crab Plan Team of the North Pacific Fishery Management Council, for the respective years within the data set and for each fishery.

f_{tf}: The expected fatality rate within the fishery constructed using data from NIOSH. It is a one-year moving average of the ratio of observed fatalities to the total FTEs employed within the fishery. In the case that this measure falls below the annual measure observed for all of Alaska, the measure for all of Alaska is utilized. More detail is provided in the paper on its instrumentation and estimation.

$fatal_{tf}$: Time and fishery specific measure of the expected fatalities within the fishery. It calculated as the expected fatality rate, f_{tf}, scaled by the number of individuals on the vessel (obtained from the EDR). Fatality data obtained from the NIOSH, Alaska Field Station. More detail is provided in the paper on its instrumentation and estimation.

$ExpRvn_{itf}$: The expected revenues from fishing in a given fishery. This was calculated using the revenues reported in the ADF&G fish ticket database and represents a one-year moving average of the vessel-specific gross revenues earned solely within the fishery studied (all other fishery data is supressed).

$days_{itf}$: The cumulative number of days that a vessel has been fishing within a given season for the target species f. This was constructed from the "trip" dates define to estimate R_{itf}, discussed above.

$Quota_{itf}$: The percentage of the total quota allocated to vessel *i* in fishery *f* that they still have not fished by time period *t*. Calculated by summing up a vessel's total annual landings reported in the fish ticket database and then calculating the ratio of unfished crab to the total landings (for each day at sea). At the end of a vessel's season this variable takes a value of zero. Therefore, it captures the percentage of their coop allocated quota that they have not fished at a given point in time.

$Strike_{tf}$: A dummy variable taking the value of 1 if a strike was in effect within the snow crab fishery in time period *t*. Data was obtained from the Alaska Department of Fish and Game office in Dutch Harbor, AK.

$VesRat_{if}$: A dummy variable taking the value of 1, 0 otherwise, if a vessel participated in respective crab fishery following the BCRP.

$wave_{itf}$: See Appendix A.2. Obtained from NOAA weather buoy 46035 in the Bering Sea.

PPR_{itf}: See Appendix A.2. Obtained from NOAA weather buoy 46035 in the Bering Sea.

$no\_weather_{itf}$: A dummy variable taking the value of 1 if the NOAA weather buoy was unavailable.

Section A.2:

The first stage regression estimated for the two fisheries is,

$$\begin{aligned} \ln(f_{tf}) &= \lambda_0 + \lambda_1 USCG_t + \lambda_2 BCRP_t + \lambda_3 USCG_{t+1} + \lambda_4 BCRP_{t+1} + \lambda_5 no\_weather \\ &+ \lambda_6 \ln(PPR_{tf}) + \lambda_7 \ln(PPR_{tf})^2 + \lambda_8 \ln(wave_{tf}) + \lambda_9 \ln(wave_{tf})^2 + \varepsilon_{tf} \end{aligned} \tag{A.2}$$

where the dummy variables $USCG_t$ and $BCRP_t$ take a value of 1 if the two-policy instruments are in effect. $USCG_{t+1}$ and $BCRP_{t+1}$ are dummy variables indicating whether or not it is year following the inception of the two policy instruments. PPR_{tf} and $wave_{tf}$ are the fishery-specific daily measures of inclement weather (icing in the snow crab fishery) and wave height and $no\_weather_{tf}$ is a dummy variable indicating whether or not weather buoy data is missing for that day. The results from this first stage regression are contained in Table A.2.

Table A.2: Instrumented Daily Risk Rate Regression Results: standard errors in parentheses for the red king crab and snow crab fisheries respectively.

Parameter	Red King Crab Fishery	Snow Crab Fishery
$\lambda_0\ (const)$	-4.7011**	-5.9957**
	(0.20)	(0.12)
$\lambda_1\ (USCG_t)$	-1.3429**	-0.5213**
	(0.18)	(0.10)
$\lambda_2\ (BCRP_t)$	-0.6521**	-0.4487**
	(0.12)	(0.11)
$\lambda_3\ (USCG_{t+1})$	0.8062**	-------[a]
	(0.23)	
$\lambda_4\ (BCRP_{t+1})$	0.1791*	0.6747**
	(0.10)	(0.10)
$\lambda_5\ (no\_weather)$	0.3735	-0.4528**
	(0.28)	(0.13)
$\lambda_6\ \ln(wave)$	-0.636	0.0009
	(0.29)	(0.20)
$\lambda_7\ \ln(wave)^2$	0.0952	0.0263
	(0.14)	(0.10)
$\lambda_8\ \ln(PPR)$	0.0035	0.2324**
	(0.19)	(0.09)
$\lambda_9\ (PPR)^2$	-0.0011	-0.0742**
	(0.10)	(0.03)
N	261	649
$\log(L(0))$	-860.18	-2,132.06
$\log(L)$	-248.61	-848.37
F-statistic	14.97	67.91

(** indicates statistical significance at the 95% level, *indicates statistical significance at the 90% level. [a]the dummy variable for the year following the USCG in the snow crab fishery was removed because the instruments it generated created a collinearity problem with other variables in Equation 1.)